PROFESSIONAL PAPERS

ON

INDIAN ENGINEERING.

VOL. IV.—1867.

EDITED BY

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ROORKEE:

PRINTED AND PUBLISHED AT THE THOMASON COLLEGE PRESS.

CALCUTTA: THACKER, SPINK & Co. BOMBAY: THACKER VINING & Co.

MADRAS: GANTZ, BROTHERS. LONDON: SMITH, ELDER & Co.

MDCCCLXVII.

JAMES JOHNSTON, SUPERINTENDENT

PREFACE TO VOL. IV.

The Fourth Volume of these Papers is now concluded,—and will be acknowledged, I think, to be fully equal in interest to any of its predecessors.

A short analysis of the Papers that have already appeared may be interesting, if only as showing the varied nature of the work occupying the attention of the Indian Engineer.

Of the 170 Papers already published, 18 refer to Railways—15 to Roads—22 to Bridges—21 to Buildings—19 to Irrigation—4 to River Improvements—3 to Water-supply—4 to Drainage—2 to Light-houses—9 to Military Engineering—14 to Surveying—and 40 to Miscellaneous Subjects, which cannot well be classified, including 12 on the Mathematics of Engineering.

Of the above number, 72 are original contributions, written expressly for these Papers, (exclusive of the few contributed by by the Editor). 12 are re-prints or translations from other works—and the remainder have been abridged or adapted from various Official reports.

No. 18, being the first quarterly No. of Vol. V, will be issued on the 1st February next, and the Subscription will be as before, Rs. 14, to those who pay in advance before that date,—*afterwards* Rs. 4 per number, or Rs. 16 for the Volume.

J. G. M.

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No. CXXIX.

ARTILLERY MESS-HOUSE—MEERUT.

THIS fine building was erected from the designs of the late Captain Atkinson, R.E. (the architect also of the Umballa Church), by J. L. Parker, Esquire, C.E., and was unfinished when the Mutiny broke out in 1857. Meerut was then the head-quarters of the Bengal Artillery, but on the amalgamation of the two services, it of course lost this privilege, and the Mess-house being too large for a mere Divisional Mess, has since been sold.

The building is of stuccoed brickwork, and the dimensions of the principal rooms, will be seen on reference to the plan and section. The architectural decorations of the interior were never completed, though the walls were adorned with portraits of famous Indian military commanders, including Lord Gough, Sir Walter Gilbert, Sir George Pollock, Sir Henry Lawrence, and others.

No. CXXX.

DRAINAGE OF MADRAS.

Abridged from a Report on a Project for the Drainage of the Town of Madras. By Capt. Hector Tulloch, R.E.

Physical Features of Madras.—The limits of the jurisdiction of the Municipal Commissioners, or *Madras Proper* as the district contained within them may be termed, extend to the south as far as the river Adyar —in a northerly direction to within a mile of the village of Trivatoor— towards the west as far as the villages of Nungumbaukum, Chetput, Kilpauk and Perambore—and towards the east up to the sea. The area of this tract may be taken at 27 square miles. The strata in parts consist almost entirely of sand, but generally of alternate layers of sand and clay. There is no rock to be found except at a considerable depth below the surface, a depth which none of the sewers which it is proposed to lay down will approach. The town stands on a sandy plain—the lowest parts being from 2 to 6 feet, and the highest from 16 to 24 feet above mean sea level. The average level of the whole of Madras may be taken at from 8 to 12 feet above the datum line.* Water is found in all parts at a few feet above or below mean sea level.

If we except the western quarter of Madras, which is so thinly populated that it is not worth while considering it as a district to be drained

* The datum line for the levels used throughout the Drawings, and referred to in this Report, is what is usually understood in Madras as "mean sea level." It is taken from a bench-mark on a stone fixed in the Escarp of the North Ravelin of Fort St. George. On the stone is the following inscription:—

"Mean Level of the Sea from May to October, 6 feet 10 inches below this Line, which answers to the Tide Gauge mark.

"Ascertained in 1821 by Major De Havilland, Acting Chief Engineer."

at present, there is no single neighbourhood which is altogether elevated above the others. In each there are high and low portions which differ from each other in height from 8 to 16 feet, but in all the districts the lowest parts, or those which must regulate the direction of the main sewers, are nearly on a dead level with each other. The lowest streets in Saint Thomè, Triplicane, Chintadrapett, Egmore, Vepery, Pursewakum, Black Town, Tondiarpett and Royapooram, which are the important divisions of the Town, are, in each instance, from 4 to 7 feet above mean sea level. It will thus be seen that there is no natural line of drainage for the town of Madras, *considered as a whole.* This is an important point, and one of the truth of which it will be well to be convinced by a reference to the Map of Madras, which accompanies this Report. Each district, however, has its ridges and valleys which can be turned to account when we take it *by itself*, and lay down its branch sewers and pipe-drains irrespective of the other neighbourhoods.

Madras may be conveniently divided into four drainage divisions.

Beginning from the north, the 1st, which comprises the districts of Royapooram and Tondiarpett, is that quarter of the Town which stretches northwards from the Railway and is contained between the Canal and the Sea. A ridge half a mile broad, and from 12 to 15 feet above mean sea level, runs north and south midway between the Canal and the Sea, and slopes gradually down on either side towards these boundary lines. The soil, to a considerable depth, is almost everywhere sand. The southern portion only of this division is thickly inhabited.

The 2nd division is that bounded by the Railway on the north, the Canal on the west, the river Cooum on the south, and the Sea on the east. It contains Black Town and Fort St. George. In Black Town there are two ridges running parallel to each other, and almost due north and south. The well known street, Popham's Broadway, which is from 6 to 8 feet above mean sea level, is the valley line between these ridges. Beginning from the east, or from the road running along the sea beach, which is from 11 to 12 feet above the datum line, the ground rises to the west for about a quarter of a mile until the first ridge is reached, which at its northern extremity, is 21 feet above mean sea level. From this ridge the ground slopes downwards to the west for another quarter of a mile as far as Popham's Broadway. From here the ground rises to the west for about a third of a mile, until the second ridge along Salay Street is.

reached, which varies in height from 13 to 20 feet above mean sea level. After this the ground falls rapidly to the west for about a quarter of a mile, or down to the canal. Of all the districts in Madras, Black Town offers the greatest facilities for drainage. The strata found below the surface consist of layers of different colored sand. Water is usually found at from 1 to 3 feet below the datum line.

There is nothing to note about the natural features of the Fort except a general fall of the ground towards the west.

The 3rd drainage division which comprises the populous districts of Vepery, Pursewakum, Egmore and Elemboor is bounded on the south by the Cooum, on the east by Cochrane's Canal, on the north by Captain Cotton's Canal, and on the west by the villages of Chetput, Kilpauk and Perambore. The most striking characteristic of this division is a general rise of the ground from the east to the west. In the southern portion this rise is regular and almost uninterrupted. It begins from the eastern part of Vepery and Egmore at 6 feet above mean sea level, and continues as far as the western limits of Madras till it attains a height of 24 feet above the datum line. Pursewakum alone has features peculiar to itself. Although it rises steadily to the west, there is a valley line running east and west from which the land ascends towards the north and towards the south. In other words, Pursewakum stands on two slopes of ground meeting in a valley—one slope faces the south and the other the north. The top of the former is from 8 to 11 feet, and that of the latter from 10 to 15 feet above mean sea level. The valley itself is from 3 to 6 feet above the datum line. On account of its great extent, it is somewhat difficult to drain the 3rd division. The strata underlying the surface soil consists in some part of sand, and in other parts of clay. Water is found at from 1 to 3 feet below mean sea level.

The 4th division is that portion of Madras which lies south of the Cooum. In it there are three populous districts, viz., Chintadrapett, Triplicane and Saint Thomè. The former slopes down from 9 to 10 feet on the west to 5 feet above mean sea level on the east. The land on which Triplicane stands is perhaps the most irregular in Madras. It rises and falls continually, and yet there is hardly an important feature to notice Perhaps, if I say the western quarter is generally higher than the eastern, a clearer idea will be formed of this district than by any detailed description I could give. For drainages proposes, Triplicane may considered to be a

flat about 11 feet above the datum line. Saint Thomè is the half of a little hill cut through the crest by the sea. The ground falls on all sides except towards the east, where it is abruptly terminated by a sandy cliff. The top of the hill is 21 feet, and the bottom from 6 to 10 feet above mean sea level. In this division, the strata are partly of sand and partly of clay. Water is found sometimes above, and sometimes below, mean sea level.

The natural drainage outfalls of Madras are the rivers Cooum and Adyar, Cochrane's Canal and the Sea.

The Cooum, which flows in a serpentine course through the heart of the town, may be considered an extensive tank. The bar at the river's mouth is the bund of this tank, and the water, when only at mean sea level, extends more than three miles inland, or nearly up to the College Bridge. From January to October the river has no outlet to the sea. It is only during the monsoon, and not always then even, that the bar is open. During the earlier months of the year the water stands at about mean sea level, but it falls gradually during the hot weather to 1½ feet below the datum line, unless there is rain in the interval. The level of the river is not affected by the tides of the sea. The heaviest monsoon does not produce a sufficiently strong current to scour the bed of the Cooum effectually. At present this river forms a large cesspool for the districts of Vepery, Egmore, Chintadrapett and part of Triplicane, all of which drain into it. Owing to the constant flow of sewage into the Cooum, and to the stagnation of the water, so large a quantity of solid filth has accumulated that the bed of the river is raised considerably above its natural level. Strictly speaking, the Cooum, for the last three miles of its length, has no fall at all. In fact, if anything, the bed slopes in an opposite direction to the course of the stream. The large drain near Government House Bridge and the main sewer of Vepery near Chintadrapett Bridge have both discharged such a quantity of filth that the bed of the river between these points is actually higher than it is for the previous mile. During the monsoon the water escapes only because the river rises above the bar and forces a breach through it. It will thus be seen that, practically, the Cooum has no outfall at all. To attempt, therefore, to convert it into a sewer is simply to make it a cesspool.

The Adyar, which forms the southern boundary of Madras, is really a smaller river than the Cooum, but it widens so considerably before

reaching the sea that its waters cover a much larger area, and at its mouth it forms a small lake. Like the Cooum it has no outlet to the sea, except for a short time during the north-east monsoon. It is even less adapted for a drainage outfall than the Cooum.

Cochrane's Canal runs in a northerly direction from the Cooum to beyond the limits of Madras. At present it is the cesspool for the western quarter of Black Town which discharges its sewage into it. As there is no current to carry away the solid matter, the bed of the Canal, like that of the Cooum, is higher than its original level.

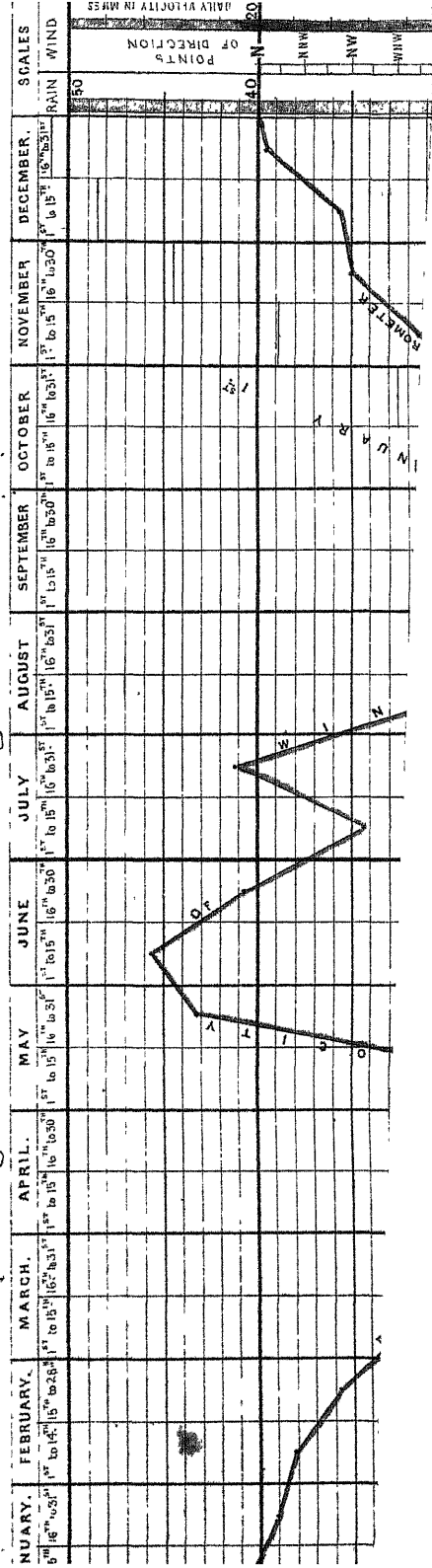
Madras has 9 miles of sea-coast. The beach throughout is flat and sandy. For the first half mile from the shore the bed of the sea slopes from 0 to about 7 fathoms or 42 feet in depth. After this the slope becomes very gradual, for at the distance of 3½ miles from the shore, the depth is only about 10½ fathoms or 63 feet.

The difference of level between high and low tide is about 3 feet only, and high and low water-mark are taken in Madras at about 1½ feet above and below mean sea level, which is invariably ascertained from Colonel De Havilland's bench-mark, spoken of before.

The two principal currents along the shore of Madras both flow in a direction parallel to the coast. The first, or that which flows from the north southwards, usually sets in about the middle of October, and continues to flow till February, or till such time as the "long shore" winds begin to blow, when the second current sets in and flows from the south northward. This current ceases about August, when variable currents and calms set in and continue till the burst of the N. E. monsoon in the middle of October. The two principal currents, following as they do the course of the winds, must, no doubt, be caused by them. If the wind, therefore, is the chief cause of the currents along the coast of Madras, I think accurate observations would prove that the currents which prevail between August and October have a tendency to flow in nearly the same direction as that which prevails from February to August. The only difference between the winds at the two periods is that there is more westing in those which blow from August to October. The velocity of the two principal currents at their full strength is computed at three miles per hour.

The general characteristics of the climate of Madras may be ascertained from the accompanying diagram.

Madras Drainage.

Half Monthly Averages of 20 Years Meteorological Observations at Madras.

The Town of Madras.—The population of Madras, according to the last statement drawn up by the Assessor to the Municipal Commissioners, is tabulated below:—

No. of drainage division.	Position of each drainage division	Important districts comprised in each drainage division.	No. of houses in each drainage division.	Population.	Average number of souls to a house.
1	North of the Railway and east of the Canal	Royapooram, Tondiarpett,	3,433	70,934	20·7
2	South of the Railway, east of the Canal and north of the Cooum,	Black Town, Fort St. George,	12,363	149,004	12·0
3	West of the Canal and north of the Cooum,	Pursewakum, Vepery, Egmore, Elemboor,	5,899	57,244	9·7
4	South of the Cooum,	Chintadrapett, Triplicane, Royapett, St. Thomè,	10,915	150,589	13·8
		Total, ...	32,610	427,771	13·1

In London the density of the population, with reference to the houses, is about 5. A Madras dwelling therefore, contains, more than 2½ times the number of people which a London house does. The density of the population of the northern portion of Madras (20·7) is extraordinary, being more than four times that of London.*

A native dwelling in Madras usually consists of one or more open courtyards, each enclosed on all sides by a terraced or tiled building. There are sometimes as many as five of these courtyards running back from the street. Both the buildings and the courtyards almost invariably slope towards the entrance, and their floors are generally raised above the surface of the road—in some streets not more than a foot; in others as much as 4 or 5 feet. These facts are very important for the purposes of this project, and will be referred to when the question of house-drainage is treated.

The greater quantity of the water used by the inhabitants is drawn from wells built in one or more of the courtyards. When there is one well only, it is usually in the back courtyard. All natives who can afford it

* Even this is rivalled by some of the villages, such, for instance, as Royapett, which has a population of 19,210 and only 620 houses,—the density being nearly 31. Is it possible that a population of nearly *twenty thousand* can be living at the rate of 31 in a dwelling—and *such dwellings?* And if this is the *average* density over the entire village, how many men, women, and children must there be in some of the houses? It is not surprising that cholera should be endemic in Madras.

buy their drinking water, which is usually brought from a distance. For all other but drinking purposes, the water in the wells is made to answer. On account of the abundance of water in the Madras wells, much more is used than might be supposed. Almost all the wells in or near the thickly populated parts of the town contain more or less organic matter. This is entirely due to the sewage of the town escaping first through the badly constructed drains in the streets, and then through the sub-soils to the stratum of sand which holds the present water-supply of Madras. Sooner or later, this water-supply must become so impregnated with the sewage as to be rendered unfit for use. In many places this has already occurred, for the wells are as offensive as cesspools, and in consequence have been abandoned by the people.* These facts, which have been brought to light by the numerous borings I have made in all parts of the town, may be relied on by Government. I bring them thus prominently to their notice, in order to show the necessity for a system of water-tight pipe-drains and sewers, which while it relieves the dwellings of all liquid refuse, will, at the same time, preserve the water-supply of Madras from contamination.†

The greater portion of the water drawn from the wells by the inhabitants is used for washing and bathing, and generally in the back courtyard, where also the cleaning of the pots and pans takes place. All the refuse water, both from the yards and from the cook-rooms, is discharged by an open channel (about 4 or 6 inches square) into the street drain. There is a privy in each house, usually on one side of the back courtyard. It consists of seats formed by low walls of brick in chunam between which the ordure falls, while the urine escapes into the same open channel which conveys away the waste water from the dwellings. All solid filth is removed by scavengers, who

* Every well in the town should be closed as soon as it is disused, for foul water never ceases to give off poisonous gases, and becomes more foul the longer it is kept.

† In some places I met with pure liquid sewage. There is no mistake about this, for the smell was so overpowering as to leave no room for doubt in the matter. As a general rule, a well dug in virgin soil in Madras will produce good water—provided that it is sufficiently far removed from dwellings. By good water I mean water not impregnated with sewage. Of a town situated, as Madras, is, on the sea coast, and with a sub-soil of sand, it would be impossible, unless a very great number of borings were made, to say where the water would or would not be slightly brakish. Wherever good water occurs, the sand is uncolored, sharp and sweet, while, in all instances in which sewage has percolated through the upper strata, the sand beneath is colored dark with organic matter, and is more or less offensive to taste and smell. It is remarkable that some wells dug on the *very margin* of densely populated neighbourhoods produced good water. A little consideration will explain this peculiarity. The chief supply of water being drawn by the inhabitants from wells situated *in* the town, the "pull" has been *from* the margin all round *to* the centre. No sewage, therefore, has flowed out of the town into these wells on the outskirts.

call at each house once or twice in the day, and deposit it in the Municipal carts which convey it away from the precincts of the town. As a rule, there are no cesspits in the dwellings. The house-drain for all liquid refuse has its outlet in the front of the dwelling, where it drops its contents into an open drain of a rectangular section (about 15 inches by 1 foot) running along the side of street. This, again, is connected further on with another drain of a similar kind, but of larger dimensions, and so on, until the last discharges itself into a sewer which lies a few feet below the surface of the ground. Both the street drains and the sewer are built of ordinary bricks set in shell lime mortar. They are as porous as they can be, and smell most offensively. Having no proper slope, they are daily choked up with filth, the removal of which is effected by manual labor only. It is for the cleansing of these drains, which are a receptacle for all the solid filth of the streets, that so large an establishment of scavengers is employed by the Municipal Department.

At present the main sewers of Madras have three outfalls—the Sea, the River Cooum and the Canal. Black Town drains into the sea, except the small portion of it lying to the west of Salay Street which drains into the Canal. Vepery, Egmore, Chintadrapett and part of Triplicane drain into the Cooum. The main sewer of Black Town has its outfall at the north-east angle of the Fort. This, being the largest, is the most offensive sewer in Madras. The main sewer of Vepery discharges its contents into the Cooum near Chintadrapett Bridge, where it has deposited a great quantity of filth in the bed of the river. The mouth of the main sewer of Chintadrapett and Triplicane is near Government House Bridge, where an effect similar to that of the Vepery sewer has been produced. Besides these main Channels which discharge both sewage and flood-waters, there are numerous small drains which have their outlets in the Cooum and the Canal.

It must not be supposed from the above that all the sewage of the Town is discharged at one or other of these outfalls. Nothing could be further from the fact. There are both individual streets and extensive areas in each neighbourhood which have no outlet at all, and where the sewage stands in open trenches round the dwellings, and stagnates from day to day, and from month to month. The only cleansing process that ever takes place is that caused by a heavy fall of rain, when the water overflows the sides of the trenches, and, in seeking an outfall, carries away some portion of the filth with it.

Dry Conservancy.—In the present state of the question of conservancy, a report on a proposal to cleanse an Indian Town by means of sewers would be very incomplete, if it did not enter into a full discussion of the new theories which have lately been started regarding dry conservancy.

Any organic substance exposed to the air is soon destroyed by oxygen of the atmosphere. The moisture is evaporated, and the body converted into new compounds of a more permanent form than those of which it was originally composed. While the body is in this state of decomposition, offensive gases are given off, but when it has taken its more permanent form the evolution of the gases usually ceases. If, however, water be poured on the substance, or it be allowed to lie in water, a second process of decomposition take place, which again ceases when all the water has been evaporated. This may be repeated many times.

The noxious smells about cook-rooms and privies arise, to a great extent, from the decomposition of organic matter promoted, in the first instance, by the action of the atmosphere, but continued by that of water. The nuisance caused by allowing refuse vegetables to lie in the streets and dry by the heat of the sun is harmless, compared with the effect that is produced by throwing them into the water lying in the drain close by.

Hitherto, in privies, all excrementitious matters have been removed by aid of water. It is now demonstrated that water can be dispensed with, and that privies can be kept much more wholesome without it. It is urged that certain substances which have the power of preventing the exhalation of foul gases should take the place of water. Of these, charcoal, ashes and clay are the most important. It is found that they rapidly absorb the moisture in excrement, and thus at once deprive it in a measure of its offensive properties. But this is not all. Even the bricks and chunam with which the walls and floors of privies are built are now objected to, inasmuch as they soon become saturated with urine or refuse water and retain for a very long time the power of exhaling noxious odours. It is proposed, therefore, either to dispense with these materials altogether by building with clay which is a deodorizer, or, at all events, to cover them with some substance, such as tar or asphalte, which does not absorb moisture—On these broad principles dry conservancy is based.

The best account of the new system is given in the Punjab Sanitary Report for 1862, by the originator, Doctor Hathaway, of the Bengal Service. The following is an extract from this report:—

"The latrines in the Punjab jails are perfectly free from any effluvium whatever, and the essential points in which they differ from the majority of those constructed for Military use are as follow:—

"A. The absence of all masonry or pucka work containing lime cement.

"B. The prohibition of all cesspools or reservoirs, and all drains or pipes, whether closed or open, leading in or out of the latrine or urinary.

"C. The prohibition of water being used to flush the ground or flooring, which is to be kept perfectly dry.

"D. The flooring being of earth, (instead of pucka masonry or stone) on which dry sand to the depth of 4 inches over a layer of well rammed clay is strewed, and the portable vessels for the reception of both fluid and solid refuse matter being deposited on the sand.

"E. The immediate removal of all refuse matter from the latrine itself, and the careful burial every evening in trenches dug for the purpose.

"F. The abolition of the practice of sprinking powdered lime in the urinaries and latrines, or in any other spot."

The other points to be attended to are—to build urinals separate from latrines—to provide thorough ventilation for both—to make all the seats in the latrines of wood and the pans of iron or earthenware—to provide a large iron receptacle with a close fitting lid in the rear of each latrine, into which the contents of the pans are to be emptied as fast as the latter are used—to keep the seats, floor, and vessels scrupulously clean—and to use charcoal and wood-ashes as disinfectors in place of lime.

Such are the main features of dry conservancy on Doctor Hathaway's principle. It is impossible to call in question the great success which has attended its introduction. The privies are clean and free from all offensive smell, and have met the entire approval of the authorities in Bengal. Like every thing else, however, of the kind, the dry system is still capable of improvement. Some important modifications, therefore, have already been made. The chief of these is the use of clay as a disinfector in place of charcoal or wood-ashes. The advantages of clay are—that it is easily procurable and exceedingly cheap—that in a dry state it is one of the best disinfectors for excrementitious matters yet discovered—and that after use it possesses a high value as a fertilizing manure. Another modification is the use of tar or asphalte for the floors and the walls of the privies. This has not, however, the advantage of cheapness. The last improvement yet made consists in the separation of the urine from the fæces. This idea originated with Doctor Thudichum, a physician in England.

The subject of dry conservancy is now attracting considerable attention

in England, and, from what can be gathered, still more attention in India, to which country it is much better suited. The great argument in favor of it is based on the fact that the most valuable manure known to man, viz., urine, will be saved for agricultural purposes. If the manured clay should hereafter possess a high commercial value, the argument will be all the stronger. So far as the application of dry conservancy to latrines is concerned, I am entirely in accord with the advocates of this system—provided that the cost of it is not be borne by the people who could never, as will be shown presently, afford to pay for it. But some of these advocates, in the heat of the excitement caused by a new and very important discovery, will not look at the question except from one point of view. The consequence is, that the most absurd and extraordinary statements are made by them as to the efficacy of the new principles, and as to the wonderful application that may be made of them. "The old system of drainage by sewers is obsolete—is a quarter of a century behind the age—is not worthy the science of the day. Dry conservancy absolutely revolutionizes the subject of drainage. We must begin *ab initio*—the great sanitary problem of the day has been solved. We are to have no more sewers and no nuisances. The town is to be cleansed on new principles, and at little or no cost to the inhabitants."

If it should be thought that this is an exaggerated account of the effect expected to be produced by the adoption of dry conservancy, the following extracts will prove that it is not. Speaking of the application of the dry system to large cities (and more especially to London) in which water drainage exists, and where it might naturally be supposed that the subversion of the present system of sewers would be attended with considerable expense, the Reverend H. Moule says—

"In the establishment of the earth sewage system no public works are required, whilst the three and a half millions being spent by the Metropolitan Board for the greater efficiency of the public works now existing, would have defrayed double the cost of all private works of the earth sewage system for London; and the manure saved, instead of wasted, would, on the very lowest estimate, have been produced a clear income of £50,000 a-year." (*Society of Arts Journal*, Vol. XI.)

The same idea has been repeated in other words by a gentlemen in Madras, who has now for some years interested himself in the question of sanitary reform. In a pamphlet, called "The Cleansing of Towns," written by Doctor Cornish, Assistant Surgeon, and Secretary to the Director General of the Medical Department, he says—

"The greatest advantage of all would be the doing away with the necessity for costly drainage works,"—and again, "Before spending some half a million of money in a system of sewers for Madras, it may be well perhaps for the rate-payers, who will ultimately have to defray the cost of the 'improvement,' to enquire whether for an expenditure of one-twentieth part of the money it may not be possible to make our chief city a model of cleanliness, and its excreta so valuable, that the cost of collection should be a mere trifle in the Municipal expenditure."

It will thus be seen that both the Reverend H. Moule and Dr. Cornish consider dry conservancy sufficient of itself to correct all the evils of a town,—those at least which arise from defective drainage. The picture has been painted in such bright colors, and has so greatly pleased the painters, that they have not cared to enquire whether it is true to nature. But the argument for dry conservancy, put in few words and cleared of everything which in any way keeps the real point at issue from view, may be stated thus:—" Because dry conservancy is the best system for privies; therefore it is the best system for towns." The fallacy arises from forgetting that in the one case, *i. e.*, in privies, excrementitious matters only are dealt with, and in the other that the same excrementitious matters form but an inappreciable amount of the filth to be removed. It is just as if a man should attempt to clean out the dust-holes of London by crushing the bones to be found in them, and then carrying away the powder as manure. Of course, he could urge that he had taken away the foulest portion of the refuse and had utilized it for agricultural purposes, and this would be perfectly true. But it would be equally true that he had left nearly all the filth behind. And this is a case exactly parallel with that of dry conservancy, when it is insisted that this system must *supersede* that of sewers. The advocates of the former keep urging that all the urine and fæces will be carried away and converted into manure, and, of course, nobody can deny the proposition which is perfectly patent. But it is also true that almost all the sewage will be left behind. In a word, though urine and fæces are undoubtedly the most offensive part of town sewage, yet in bulk they do not amount (as in the case of London for instance) to more than $\frac{1}{200}$th of the whole. This is so easily proved, that it can escape the observation only of persons so wedded to a new theory, as to be unable to look adverse facts in the face, but it explains at the same time why those who have to remove the sewage in England do not consider the extravagant proposition to do away with sewers worth refuting.

The average of the returns of the Metropolitan Water Companies shows that the quantity of water used in London per head of the population is 44 gallons = 440 lbs. daily. The average quantity of excrementitious matter voided by each individual may be taken at 2 lbs. of urine* and $\frac{1}{4}$ lb. of fæces,† or together to $2\frac{1}{4}$ lbs. daily. This is equivalent to $\frac{2\frac{1}{4}}{440}$ = very little more than $\frac{1}{200}$-th of the waste water. Suppose, however, that in Madras, 5 gallons only, or 50 lbs. of water are used per head of the population, then the excrementitious matter will be $\frac{2\frac{1}{4}}{50}$ = not *one-twentieth* of the water. Mr. Fraser, C.E., informs me that he proposes to supply 20 gallons or 200 lbs. of water per head of the population. If this is done, the excrementitious matters will be very little more than *one-hundredth* of the waste water to be removed. The proportion of night-soil to liquid sewage in Bombay is calculated at 1 to 775.

It might, however, be supposed, that, in answer to all this, it would be contended that, if sewage were deprived of excrementitious matters, it would not be offensive, and might lie harmless in the drains. This certainly would be an extraordinary argument to urge with any one acquainted with the mode of conservancy adopted in Madras, where already almost all the fæcal matter is removed by the Municipal carts, and the smell in the streets is, nevertheless, perfectly sickening. But still it would be taking the bull by the horns. The advocates of the dry system, however, take up no such position. On the contrary, they urge with all the force they can, that *water! water!* is the chief cause of the evils in privies—prohibit its use, and the privies will be clean and wholesome. Indeed, they insist that waste water from dwellings is only less offensive than *excrement itself*. The following extract from Dr. Cornish's pamphlet will show that I do not misrepresent the views of these gentlemen:—

"In tropical countries the putrefactive process, *when water is present,* proceeds with a truly wonderful rapidity. Not only do animal excretions decompose with great speeds, generating poisonous compounds to pollute the atmosphere, but common house-sweepings, cook-room refuse, &c., when mixed with water, become in a very short time an intolerable nuisance. Even the waste water from bath-rooms, if retained for a few hours in a cesspool or reservoir, will be almost as offensive as excrementitious matters themselves."*

Now, is it not strange that the same people who see so clearly the

* *Vide* page 679 of Fawnes' Manual of Chemistry, 7th edition.

† According to Baron Tiebig.

‡ *Vide* page 6 of Dr. Cornish's Pamphlet.

danger of allowing waste water to stagnate and poison the air, will not admit the necessity of making provision for its removal? The project now submitted to Government, like all drainage projects, has for its object the removal of this very waste water without retaining it in cesspools or reservoirs. When it is shown that this can be done effectually in all towns by a cheaper method than that of sewers, of course that method should and will be adopted, but until then there is little doubt that the system of drainage by sewers will prevail in India as in Europe.

It will thus be seen, that, in advocating the universal application of dry conservancy, it has been entirely forgotten that the use of water, which should be *prohibited* in privies, should be *encouraged* in houses. By strict supervision, water may be excluded from the former, but, so long as we are human, it must be used in the preparation of our food, and for the cleansing of our persons and our dwellings. To those who say—"no public works are required," "do away with your sewers and adopt the dry system," is it not natural, under all the circumstances mentioned above, to reply,—"in that case, what shall we do with our waste water, for you yourselves say it is only less offensive than excrement?" The advocates for the universal application of dry conservancy are bound to answer this question before they make the extravagant proposal to cleanse a town solely by building model privies.

But in order that Government may understand all that is proposed to be done in Madras, I will try to put the system of dry conservancy as a whole before them. Public privies of an improved design are to be built in all parts of the town, and at such convenient distances apart as shall induce the inhabitants to use them.

"One side of the building is for males, and the other for females, twenty of each might be accommodated at one time in the privy. The urine, voided into a channel against one wall of the building drains along an asphalted gutter (the whole of the interior, floor and walls is to be asphalted), and after being filtered through a moveable screen containing coarsely powdered charcoal, is finally received into an asphalted reservoir outside, which reservoir is to be nearly filled every day with dry earth, to allow of the urine being absorbed and subsequently carted away without decomposition or offence. The object of the filtration through charcoal is to remove the mucus of the urine, by which arrangement it will not begin to decompose for a period of 24 hours or more.

"In the privies, the following arrangement is suggested. In the space allotted to each person the toty will keep a flat, saucer-shaped chatty, painted or soaked in coal tar, and well dried previous to use, to receive the solid excrement. These chatties should always contain a little dry earth or wood-ashes, and after use the evacuation

should be immediately covered with a small quantity of *wood-ashes*, kept in readiness for the purpose within the enclosure, and the whole removed to the shed outside, where the chatty should be emptied and the mixed ashes and fæcal matter put into an iron tub or basket for removal. It will be observed in the plan, that separate provision is made for the reception of the urine passed during defecation, in an asphalted channel, which conveys it to the urine reservoir outside."*

It is expected that the excrementitious matter, after being converted into manure, will be gladly removed by contractors who will find it pay them to use it on the lands about Madras. It is moreover considered that, on account of the highly deodorizing properties of clay, no nuisance will be caused by the construction of the latrines even in the heart of the town, and that the removal of the manure through the streets will give no offence.

It is evident, on a *primâ facie* view of the matter, that the entire success of the scheme will depend on a universal use being made of the latrines. Because, if some people use them and others do not, we shall have both the expense of the new system and the nuisance of the old. It is not shown, though, how this end is proposed to be secured. Whether the people will be compelled by law to frequent the public privies, or whether the use of them is to be entirely voluntary. It would not much signify, however, if a dozen laws were passed on the subject, for the State, having no control over the individual in his dwelling, could not prevent his evading the law in it if he chose to do so.

We will assume, therefore, that it is intended that the question should be decided by the common sense of each individual. But common sense appears to me to be against the universal use of public latrines, so far at least as women are concerned. Can it be expected that any respectable man will permit his wife or his daughters to leave the privacy of their home —to walk, say, 150 yards in dry and wet weather along a public street to a public place for *such a purpose*—to mix there with perfect strangers— and to perform such a duty in their very presence. Yet, if the women as well as the men did not use the privies, what measure of success would attend the introduction of dry conservancy? The advocates of this system may point to the fact, that the existing public latrines are made use of by women, which is perfectly true; but is it by women of the very lowest classes, and by such of them only as have no backyard or enclosure of any kind to resort to. And even these women are driven to the public privies

* *Vide* page 16 of Dr. Cornish's Pamphlet.

only by the strict supervision of the Police. Instead, therefore, of encouraging what every one will admit is a proper sense of decency, dry conservancy proposes to lower all classes to the same degrading level. Surely this is a backward step in civilization. Let it be remembered, too, that children and young girls are to be subjected to this public ordeal. To what a state of morality must this lead?

Even in England, where every water-closet at the Railway Station is a separate room and has a lock and a key in the door, the prejudice even among men against it is so strong that nothing but the greatest necessity will induce them to use it. I am aware that this prejudice arises in a great measure from the fact that infectious diseases are easily propagated by the water-closet system, but it arises also from other causes. In spite, too, of every care that might be taken in the public latrines in Madras, it would be impossible to prevent some of those infectious diseases spreading amongst the people. They must all wash at one and the same place. It would not be possible to have large tanks in the heart of the town, and, if these were erected, the cost of the system would be enormous, as will be shown presently.

Besides, how will it be possible to arrange for the wants of the sick, who will not be able to leave their dwellings, and who, at the rate of five sick in every hundred of the population, will amount in number to $\left(\frac{430,000 \times 5}{100} =\right)$ 21,500 souls—producing daily more than 21 tons of excrementitious matter. Where, too, will the line be drawn amongst the community as to the use of the latrines? If natives *must* use them, so must East Indians, and so must Europeans. There cannot be one law for the native and another for the European. And will Europeans and East Indians submit to such an arrangement? Will they sit on the same seats with natives, and in the same manner? If not, it will be necessary to provide separate latrines for the different races, and this again will add to the cost.

In rainy weather, moreover, how will it be possible to induce the people to go to the privies? This is the very time, too, when the offensiveness of urine and fæces will be greatest. The difficulty of carrying out dry conservancy in wet weather has been partly foreseen by Doctor Cornish, but not entirely provided against. He says, "In wet weather a supply of dried earth should be kept ready prepared *under cover*."* This is all very well

* *Vide* page 18 of Dr. Cornish's Pamphlet.

so far as the clay is concerned, but what will be the use of it if people do not frequent the latrines at that time?

In advocating universal dry conservancy, people are too apt to be led away by the success which, *under certain conditions*, has attended its introduction into India. Whenever it has been tried on a limited scale, as, for instance, in Barracks, Jails, Hospitals, &c., its success has been complete. But the reason is so obvious, that it is strange it should be so often overlooked. If Government have a number of troops, or prisoners, or invalids whom they can easily keep under discipline, every individual can be compelled to make use of the latrine. The very fact of a man entering a hospital is an admission on his part that he is willing to submit to the regulations of the place. But the question assumes a different aspect altogether when Government have to deal with a mixed population of half a million men, women, and children, scattered over many square miles of country—living in all kinds of houses—and over whom, as soon as they are within their own doors, Government can exercise no control whatever. How can a universal use of public privies be enforced under such circumstances.

But Dr. Cornish claims one great advantage for universal dry conservancy, viz., that it is much cheaper than the sewer system. This is certainly the most unfortunate mistake that has yet been made by the advocates of the new theory, and the one which will tend to damage it more than anything else. He says:—

> "Before spending some half a million of money in a system of sewers for Madras, it may be well perhaps for the rate-payers, who will ultimately have to defray the cost of the 'improvement,' to enquire whether for an expenditure of one-twentieth part of the money it may not be possible to make our chief city a model of cleanliness, and its excreta so valuable, that the cost of collection should be a mere trifle in the Municipal expenditure."*

It will thus be seen that 2½ lakhs of rupees is the sum set down for cleansing Madras thoroughly according to the new principles. It has always been maintained by the Engineering profession, that, whatever objections might be raised to the sewer system, it was the *cheapest* means known of disposing of sewage. A sewer, once built properly, will, with occasional trifling repairs, last for centuries. An inconceivable quantity of water may be passed through it. It will work as well in the night as in the day.

* *Vide* page 23 of Dr. Cornish's Pamphlet.

With fair play the supervision required is most trifling. It is necessary, therefore, to ascertain if dry conservancy is cheaper.

[Calculations are then gone into by Captain Tulloch, which show that the cost of the privies, urinals and earth sheds for the whole city, will be not less than 26 lakhs of rupees; that the total *monthly* cost of the establishment for looking after them will be Rs. 13,545, besides the cost of carting away the excrementitious matter, which will be Rs. 6,840 more.]

Objections to Sewers answered.—Before passing on to a description of the project now submitted to Government, it is necessary that the general objections to the system of drainage by sewers should be met. Fortunately, these objections have been very fully stated by the same Officer who has pleaded so strongly on behalf of universal dry conservancy. When the arguments on both sides of the question shall have been fully stated, it will not be difficult for Government to decide between them.

At the present time, when sanitary questions are attracting great attention, it is of vital importance that the general principles of water-supply, drainage, barrack construction, &c, should be thoroughly discussed. If mistakes are made at the outset in carrying out large and important works, the chances are that they will be repeated over and over again, and at an enormous cost to Government. Whereas, if the correct principles of any one subject are clearly defined, there is every hope of their universal adoption. As this is the first project which has been submitted to the Madras Government for the complete drainage of a large town in the Presidency, it would be a grievous error to carry it out if it should be based on erroneous theories. On this account, therefore, I have considered that I should be discharging my duty to Government better by omitting nothing in this Report bearing on the question of drainage, than by confining myself strictly to the immediate subject matter.

The reason why dry conservancy has "taken" better with the Indian than with the English public is, that the physical conditions of this country are so much more favorable to its development. England has a damp, while India has a dry, climate. The heat of the sun, which is so important an agent in the dry system, acts perfectly in India. Moisture is rapidly absorbed, and clay easily dried. In England, the damp air and the continued absence of sunshine for many days together are obstacles, though not insurmountble ones, to the perfect working of the system. In

England, moreover, it is raining more or less constantly throughout the year, while in India the entire supply of rain is obtained in a few days. The rivers in England are flowing all the year round. Those in the south of India are dry for some months. All these facts are urged as arguments against sewers.

But if sufficient water is stored in the monsoon and when the rivers *are* flowing, there need be no lack during the hot months. To prove that we have not sufficient water, it is necessary to show that the rain-fall, the source of all water in every country,* is deficient. Yet what is the case? The rain-fall in India on the average is double that of England. It is true that the evaporation is greater, but after making every allowance for loss due to this cause, there is an enormous balance of water available for the use of man. Has India, then, any reason to complain? Every effort which has been made to store water in the country is a standing protest against the statement that we have not sufficient water. The success of even small tanks is very great. Would Government otherwise keep them in repair? What works can be better adapted to the purpose of store-reservoirs than large tanks and anicuts? It is a great mistake to suppose that all the towns in England draw their water-supply from large and ever-flowing rivers, and that these large rivers are necessary to works of drainage. Numerous towns in England are supplied with water from store-reservoirs exactly similar to the tanks of India, and their success is complete.

I believe that the following extract from a letter to me by W. Fraser Esq., C.E., expresses briefly the general opinion of all Engineers in this country:—

"I have had occasion to consider this subject a good deal, and I am of opinion that abundance of water can be had everywhere in the South of India if proper means be adopted to secure it, and that it is difficult to conceive a case where money spent in this way would not be a profitable investment."

So far, therefore, as drainage depends on water-supply, is there any reasonable cause to object to sewers?†

As to the quantity of water required for flushing sewers, which Doctor Cornish supposes must be very great, the following extract from a Report on the Drainage of Bombay, by Robert Rawlinson, Esq., C.E., "who," ac-

* I am, of course, speaking generally.

† The more I enquire of my brother-officers as to the possibility of storing water for irrigation and other purposes up-country, the stronger assurance I obtain of the facilities for doing so.

cording to Sir Charles Wood, "has earned a high reputation for skill in that branch of Engineering,"* will show that very little water suffices for the purpose:—

"During the dry season in Bombay the sewers should be regularly flushed with fresh water. The volume of water used need not be large, nor the expense very great."................. "At the great hospitals on the Bosphorus, used by the British Army during the Crimean war, large wine casks were used as flushing tanks. These were placed over the heads of the sewers, and were regularly filled from the Bosphorus by laborers (natives) who carried the water to fill the casks, then an orderly suddenly opened a valve, some 6 inches square, which discharged the water, about 250 gallons, in a few seconds. These sewers were large and rudely constructed, with flat bottoms, some 3 feet wide, but they were flushed free from deposit by the means described."†

What could be better for sewers in this country than the ordinary water-carts used in Madras filled by the aid of *pecottahs*? The large sewer in Bangalore is flushed throughout the year with water supplied from an ordinary tank.

The sewers proposed in this Project will be as perfectly smooth as skill can make them, and not one of them will be so wide at the bottom as the above-mentioned, while most of them will have a diameter at bottom of only one foot. So far as Madras is concerned there need be no anxiety about a deficiency of water for flushing purposes. I could only wish that there was not so much available under the surface as there is, because the cost of building the sewers is porportionately increased. The flushing arrangement will be most complete, and will cost nothing after the sewers are once built.

The next objection to sewers is condensed in the question, "Where is the sewage to go to?" And the reply suggested is, "The rivers."

"The great rivers, the Godavery, the Kistna, and the Cauvery, which contain more or less water throughout the year, do not run near to many populous towns, and are practically unavailable for the purpose. Along the Coast, sewage might probably be pumped into the sea, but the difficulty would still remain with inland towns, such as Bangalore and Secunderabad."‡

The error in this reasoning lies in supposing that rivers, as outfalls for sewage, are a *necessary* part of the sewer system. They form no part of it at all. It is, indeed, unfortunate that in so many instances in England

* *Vide* page 97 of "Correspondence on the subject of the Drainage of Bombay."

† *Vide* page 101.—*Ibid.*

‡ *Vide* page 7 of Dr. Cornish's Pamphlet.

sewers should have been led to rivers, but this is not the fault of the sewers but of the people who built them.

All sewage, and especially in this country, should be returned to the soil—to the same place where the solid manure of dry conservancy is to be conveyed. Those who are so anxious to preserve urine and fæces as manure should not forget that, after all, they cannot manage in India without water, which must descend as rain or be raised artificially, before crops can be made to grow. The only difference, so far as the agricultural part of the question is concerned, between solid manure and liquid sewage, is that in the first case you have an article which is almost useless by itself, and in the second you have nearly all that is required to produce anything. The mistake lies in reasoning from England to India without considering the different conditions of atmosphere, soil, &c., prevailing in the two countries. In England it is raining more or less throughout the year, and the first question which the agriculturist puts to himself is, "How shall I get rid of the water?" In India it rains for about 20 or 30 days, and the first question the ryot asks is, "From where shall I get water?" The soil in England in its normal state is saturated with moisture, and every effort is made to keep it dry. The soil in India is dry, and every effort is made to keep it moist. Sewage is manure in a diluted state. But its use even in England, *now that they understand how the sewage should be applied and what crops should be grown under it*, is almost uniformly successful and is advocated by the greatest authorities.

The case of Edinburgh, where, by the use of sewage, land has risen in yearly rent value from £2 to £6 per acre to from £30 to £40 per acre (Scotch) is so well known that I need not dwell on it. About Milan land yields a net rent of £8 per acre. The meadows are mown four times in the year for stable feeding, and besides this, three crops of hay are yearly obtained by sewage-irrigation. At Clitheroe, in Lancashire, it has been proved that the fertilizing properties of sewage water are nearly four times as great as those of common farmyard manure. At Mansfield, in Nottinghamshire, land has risen in rent value from 4*s.* 6*d.* to £14 per acre. At Ashburton, and at other towns in Devonshire, liquid sewage has been applied for 50 years, and the yearly rent of land has reached £8 to £12 per acre, while land not improved with sewage yields a yearly rent of only £1½ to £2 per acre. But all these, though well known, are old instances of the effect of the application of liquid sewage. The

most recent instance, and the one which is attracting so much attention in England, and which, it is supposed, will at last decide the question in favor of the use of liquid sewage, is that of Croydon. The inhabitants have been *compelled* to make use of the sewage of their town for the irrigation of land. The result is, that enormous crops of green food have been obtained, and this without any nuisance or inconvenience, while at the same time the surplus water after irrigation is found, on entering the River Wandle, to be purer than the water of the river itself.

The application of sewage to land is, like other branches of agriculture, a science of itself. Occasional failures will occur, and many more must be expected until the subject is better understood, but these are or will be due to want of knowledge and judgment on the part of those who use the sewage and not to the thing itself. Every year the use of liquid sewage in England increases, and the *belief in its value is now general.* It is not a perfect manure, but no substance can possibly be a perfect manure. All that should be contended for sewage, is that it has great fertilizing properties.

Baron Liebig says—

"The employment of sewage in agriculture would make it possible to bring large tracts of land into cultivation, which hitherto, owing to the expense of tillage, has been laid waste and neglected: * * * * * *

"It is neither fantastic nor ridiculous to believe that, without purchasing foreign manure, by a judicious utilization of the sewage of towns and villages, England would be able to dispense with the importation of food from abroad."*

If all this can be declared of England, where already there is too much moisture in the soil, what wonderful fertility might be produced with sewage in India? Pour water on the land—flood it if you like—and what is the result? A succession of crops. Would not better crops be secured with water mixed with manure? It may be granted that solid manure, bulk for bulk, is more valuable than sewage. But that is not the point at issue. The point is, whether solid manure in a dry country like India with 20 or 30 wet days in the year is worth 20 or 100 times its bulk of sewage, which, according as 5 or 20 gallons of water are used per head of the population, I have already shown, it will amount to. And even this is not putting the case fairly, because every pound of solid manure will have to be carried to the fields, and then spread and mixed with the soil by manual labor, whereas liquid sewage can be applied to the land by sim-

* *Vide* page 657, Vol. XI., of "Journal of the Society of Arts," for August 21st, 1863.

ply opening a sluice. Thus drainage works in India should be looked upon as works of artificial irrigation—that they will ultimately become so, I have no doubt whatever.* The land will make its claim good to every drop of water and every ounce of manure, in spite of all that may be done to prevent it. It will, in the proper place, be shown in how remarkably favorable a position Madras is situated for the utilization of its sewage.

The next argument against sewers will be seen from the following extract:—

"India, for many months of the year, is a dry and thirsty land, so greedy of moisture, that unless sewers be built of some less absorbent material than brick and mortar, the soil will take up all the watery parts of the sewage, leaving the solids to choke up the artificial channels. This state of things obtains in the town of Madras throughout the hot and dry seasons, and it is no wonder that, under such circumstances, the odour of our drains should have obtained a proverbially evil repute.

* * * * * * * *

"Of Madras it has been averred by competent authority, that before the construction of drains, its abominations were not so noticeable as they have since become. The attempts hitherto made to follow in Indian towns the European model of sewerage, have undoubtedly had the effect of making those towns more pestiferous than they were before sewers were thought of."†

No attempts, that can really be called such, have yet been made to follow the European model of sewerage. It is notorious that in Madras the worst kind of bricks and ordinary (not even hydraulic) mortar have been used. The mortar, moreover, is made of *shell* lime. It is not extraordinary, therefore that the drains should be a nuisance. But to argue that because bad materials are used in Madras all sewers are objectionable, is tantamount to saying that because bad flour is sometimes used all bread is unwholesome. If proper bricks and proper hydraulic mortar are used, sewers could not be objected to. In the project now submitted, I have provided that steam-pressed bricks only shall be used, and that they shall be set in hydraulic cement, and that the sewers shall be lined *throughout* with a coating of asphalte. The subject of materials is so entirely a professional one, that I will not pursue it further in this place.

There is really no similarity at all between the European model of sewerage and the system which has been carried out in Madras. It is absurd to compare the two. In Madras the street drains are all open—in England they are always closed. In Madras the drains are near the

* Already the sewage of Bangalore fetches money; it is true a very small sum, but time must be given to enable the people to learn the full value of liquid manure.

† *Vide* page 8 of Doctor Cornish's Pamphlet.

surface—in England they are at a considerably depth underground. In Madras no attention whatever is paid to the slopes of the drains—whereas in England the inclinations are regulated on scientific principles, and the drains are laid with almost mathematical precision.

Now, when it is remembered that the whole question of drainage is one of slope—that it is necessary that every single drain and pipe should be laid with the utmost care and at such an inclination as shall enable it to keep itself free from deposit—and when nothing of this kind is attempted in Madras, where the drains are built solely with reference to the slope of the surface of the ground, and not at all with regard to the inclination which each drain should have—is it surprising that the present drainage system should be a failure and a nuisance? It would, on the contrary, be extraordinary if it were otherwise. The Madras sewerage has failed simply because it is totally *unlike* the model system adopted in England. So far, therefore, from being discouraged by the present state of the Madras drains, we should rather be encouraged by it to give the European system what it has not yet had,—a trial.

The next objection to sewers is, that they create a great nuisance, and this, if it were true of a proper system of sewers only, and not of other systems of conservancy, would certainly be a more valid one than any yet brought forward. But unfortunately, this nuisance is an objection to all systems of conservancy. Where foul matter is disposed of, there must be more or less smell. Latrines on the dry conservancy principle are not inodorous, but merely less offensive than those in which water is used.* And dry conservancy after all contemplates merely the removal of excrementitious matters, and leaves the question of the nuisance caused by refuse water untouched. So what is to be done? Sewers remove *all* liquid refuse with a little nuisance. Dry conservancy, so far as it goes, removes some of the refuse with, say, less nuisance,—but unfortunately it does not go very far, for it leaves at least nineteen-twentieths of the refuse behind. We are merely on the horns of a dilemma, and must choose between two evils. Of these, sewers are incomparably the less evil, because, at least, they do form a *complete* system, and the effect of them is known, but dry conservancy is merely a partial *expedient*, and the fearful consequences of leaving waste water stagnating about our dwellings

* If there is any doubt of this, a visit to the model latrine on the north bank of the Cooum near Poodoopet will convince the most sceptical.

cannot be foreseen. To combine the two systems, *i. e.*, to utilize excrementitious matters in public privies on dry conservancy principles and to have a system of sewers, would be impossible. The expense of such an arrangement would ruin even Bombay itself.

Those who exaggerate the nuisance caused by sewers should remember that in a very short time this will be no argument at all. The subject of deodorizing and disinfecting sewage is in a most hopeful state. Already it has been announced that the Thames *can* be disinfected for £20,000 a year. That is not a large sum for so great a sewer. Mr. Norton's experiments in Madras, moreover, have not been so unsuccessful that it can be said sewers will never be disinfected cheaply; that they *can* be disinfected, there is no doubt. The question now has resolved itself into one of expense only. Some of the greatest analytical chemists of the day have declared that it is quite possible both to prevent any smell arising from sewers, and to retain at the same time the manuring properties of the sewage. Indeed, in England, antiseptics *are already used* with the best effects. For Madras, I have arranged that the sewers shall be throughout ventilated through charcoal disinfectors, a plan which is found to answer admirably in Europe.

A great authority on Indian Sanitation (Dr. Norman Chevers, of Calcutta) has been cited as being opposed to the principle of sewers. It is best therefore to quote what he really *does* say (*vide* Indian Annals of Medical Science, No. XVII.)

"The feculent excreta and every kind of solid filth, road scrapings, and sweepings, stable-litter, the refuse of knackeries, markets, tan-yards, urinaries, gardens, cook-rooms, &c., &c, &c., being collected and carried away in conservancy carts; the fluid sewage of the city, that is, all liquid matter from manufactories, markets, gas-works, cook-rooms, &c., &c., which could not be removed in conservancy carts, being properly diluted and flushed onward with an abundant supply of fresh water, at high pressure; should be voided by a system of underground sewers of very moderate capacity, the inlets of which ought to be secured against the entrance of storm-water and of all solid refuse; while the whole rain-water, except such portion of it as may be required to flush the sewers, &c., should be carried off by a system of open surface drains."

I beg respectfully to draw the attention of Government to Doctor Chever's views on the subject of drainage as meriting great consideration at the present time. I believe them to be the true principles on which drainage works in this country should be carried out, and the only broad principles on which success can be ensured at least cost. I arrived at the very same

conclusion as Doctor Chevers has done, very soon after I commenced the preparation of this project for the drainage of Madras, and, further on in this Report, I have brought forward all the facts which I had collected to show the difficulty of following the English plan of sewerage, in Madras or in those parts of the Presidency where the total rain-fall was obtained in a few days, and the enormous expense it would entail. The proposition now made for the drainage of Madras, viz., to separate rain-water from sewage—to carry away the former by open surface drains, and the latter by sewers of moderate capacity, will, I trust, be received by Government with greater favor, now that it is put forward by an eminent man, than if it had been made myself alone.

(To be continued).

No. CXXXI.

IMPROVEMENTS IN NAVIGATION OF INDIAN RIVERS.

By W. H. LONGMORE, ESQ., *Assist. Engineer, Ganges River Works.*

THE Navigation of our Indian Rivers has attracted a great deal of attention, and the question has often been raised whether it is possible to improve these large streams and make them more thoroughly subserve the interests of trade and commerce generally. I think this can be answered satisfactorily.

The uncertainty and danger attendant upon the navigation of the Ganges in the dry season are, as is well known,—due to the ever changing current, and shifting shoals, which abound in the whole course of the stream, and the want of sufficient depth at times for crossing these shoals. During the rains there is abundance of water for navigation, and deeply laden boats can then pass over the sand banks scattered along its bed, which are high and dry at the lowest state of the river.

These sand banks can be seen to a vast extent at the entrance of the Bhagurruttee, extending for some miles, and forming a complete bar to it. This branch of the Ganges is rarely open even for boats of the least draught during the dry season. That it should be kept open is of great importance, and which is fully recognized by the Government expending large sums annually for this purpose, sometimes successfully, but as a rule unsuccessfully, except, so far as preventing it closing so soon as it might if left to itself. The Bhagurruttee connects Calcutta with the main Ganges, and in the rains is used by the large river steamers; and by all the country boats conveying produce from above Rajmahal to Calcutta, whose draught in many instances is three times that of the steamers. As the river falls, the larger boats are forced to go down the main stream; next the steamers are obliged to give it up, and go round the Sunderbunds,

until at last, when the river is at its lowest—supposing the entrance is open—boats of 20 or 24 inches draught can only pass through.

The works employed to keep it open, are identical with those employed for deepening shoals in the main stream, and may be called native works, as there is not a particle of English Engineering about them.

They consist of bamboos fixed at intervals in lines inclined to the stream —along these others are tied longitudinally, on which mats are hung facing the stream, the rear being supported by struts. In constructing these, two points have to be attended to. The piles after being well shaken into the sand should be driven down with mallets, and in placing the mats a space shown at AB must be left between their lower edge and the bed of the stream—the mats over-lapping one another. Such a work is called a *bandel*.

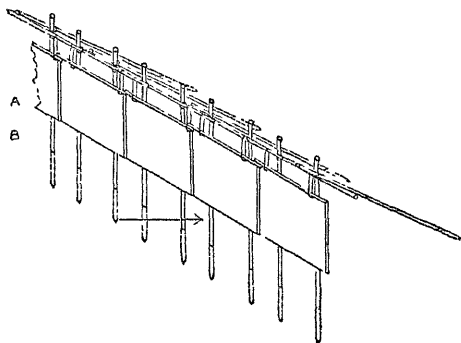



Fig. 1.

The principle of its action is to collect the sand carried by the stream and deposit it at the back of the bandel. If the mats were carried to the bottom this would not be the case, and hence a space is left for the water to pass carrying the sand with it, and which as a rule, cuts a deep trench in front of the bandel, as shown in Fig. 2.

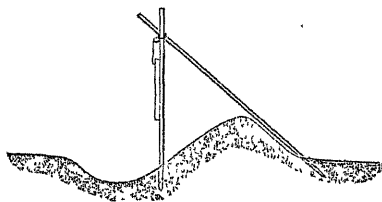
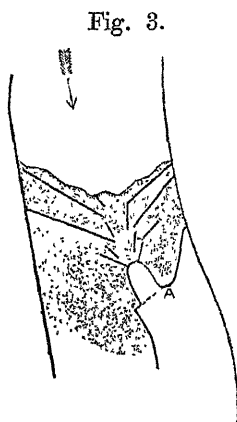



Fig. 2.

The defects of this system are—1st, its buoyancy; 2nd, its porousness; and 3rd, its limited application, due principally to the first defect. If the materials were heavier, then it might be placed in deep water; but to retain it for any length of time, even in the shallowest parts of the stream, it is necessary to have the piles constantly driven down, as they are always liable to be washed up and floated away. I have seen whole lines carried away in one night from this cause.

The second defect, arising from the openness of the mats, is not so detrimental as the former. A certain quantity of water passes through them without being of the slightest use. On the contrary, its effect is rather injurious; for it increases the current at the back of the bandel, and assists in carrying off the finer particles of sand, which would go towards the accumulations in the rear. In some cases it is requisite to stop the current altogether, under these circumstances the mats but very imperfectly perform their intended office.

Bandels are generally arranged as shown in Fig. 3, which represents their position when first laid down. After they have been in operation some little time, the sand will commence to accumulate at the lower end and will fill up as far as A. To meet this lengthening of the channel, other lines of bandels have to be added, and continued as far as the filling up extends.

Fig. 3.

Seeing that the common bandel was utterly useless for working in a deep and strong current, I considered whether something might not be done with its materials to form a construction that would answer this purpose. The plan I adopted was very successful, and enabled me to advance into the centre of the Ganges, and turn a part of its current in the direction it was required; and this too, when it was flowing some five miles per hour, and 15 feet deep.

The great difficulty to contend with in its construction was the same as with the common bandel—the buoyancy of the material—but when once constructed, there it remained, and gave not the least alarm about its being carried away by the current. The construction is fully shown in Fig. 4.

These *groins* were formed by a number of piers, triangular in shape, placed at intervals and tied firmly together.

Each pier was constructed thus—3 piles were driven to form as near as possible an equilateral triangle; over these a triangular curb, crossed with small bamboos, to form a sort of gridiron, was dropped and forced to the bottom.

The upper part was then tied to form a triangle similar to the lower, and piles were driven at intervals along all these sides and the interior filled with sand bags, made of mats rolled into a cylindrical shape and well rammed.

After this the mats were applied, measuring 20 feet × 3 inches, made by

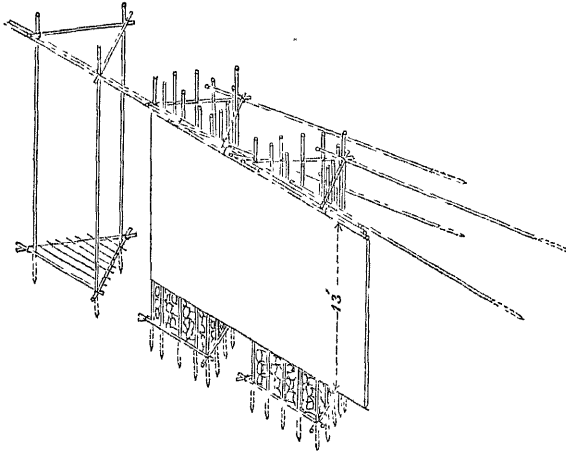
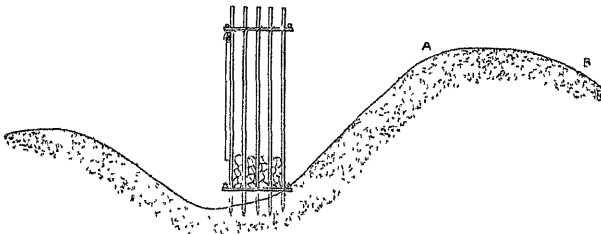
Fig. 4.

tying the small mats on to a frame work of bamboos. As soon as one side of the frame was fastened to the piers, the boats carrying them were withdrawn, and the force of the current carried it close in; often with such force as to make the whole groin creak and bend again. To prevent the escape of any of the sand bags, the lower curb was fastened to the top one with stout string.

Fig. 5.

The triangular shape of the piers was found advantageous. The water rushing through the opening between the piers spreads out on either side, cuts away the sand and tends to tilt the pier over—this is counteracted by the struts, and its connection with the other portions of the

work—the sand under and in front is then cut away, and the pier sinks; in some cases inclined forwards, in others to the rear, but generally vertically, depositing a great mass of sand behind (*see* Fig. 5). In a depth of 12 feet, I have witnessed 10 feet shoaled up in the course of a couple of days, extending in one line for a distance of 150 yards, and at least 15 feet broad.

All the coarser sand is deposited at A—the finer is carried and deposited in the direction of B.

Position for Works.—It is impossible to lay down any rule or number of rules that shall be applicable to all the various phenomena of the river,—for fixing the works.

Each reach of the river requires different treatment at different periods of the same season, and in each year invariably so. In laying down any principle for guidance, the chances are that the physical characteristics on which it is based, may not be fully recognised, and it will therefore be a failure.

The contour of the banks may be safely taken for guidance when the river is high. The deepest and strongest current will run along its concave side, from whence the bed will gradually slope up, forming a sand bank or shoal on its convex side. And a shoal generally exists running obliquely across the river, from the point where the current passes, and from one bank to the other. But when the river is low, the banks afford very little indication where the current is deepest and strongest.

Before deciding upon any line of action, it is very necessary to take soundings regularly, to ascertain any change that may be taking place in the bed of the stream, and to what part it is likely to tend. In case it has to be diverted from one direction to another, it is best to work in curves as much as possible, that the water may lose but little of its initial velocity; but where the channel can be made straight and preserved so, it should be carried out accordingly. For diverting the main stream of the Ganges, I used curved groins, and found them answer exceedingly well. I arranged them as shown in Fig. 6.

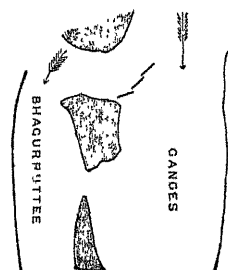



Fig. 6.

It is often difficult to determine the effect a proposed groin may have

when there are a number of channels and currents. This will be shown on reference to Fig. 7. A strong current runs down B to A, passes and divides into two currents D, E. A groin at A, it might be supposed would divert more down to E: it may however have a contrary effect, for the current at A finding itself arrested would turn off in the direction C and form a curve to F, a direction less favorable for the current down E. Then it might be urged that closing D would answer this end. Even this is problematical. For the draw on the current down B, which must be kept deep, would be slackened, and it would tend to silt up, except it was closed long before the river reached its lowest.

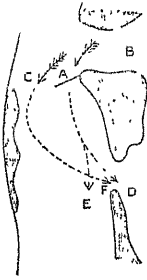



Fig 7.

In deepening a shoal the two nearest and deepest portions of the upper and lower reaches should be connected, even though somewhat oblique to the current, when the quantity of sand to be carried off is less than where the current is more direct. For, apart from the greater quantity of sand to be removed and the tendency of the stream to economise its own force, it will be found, that the relative levels in the two reaches are different (*see* Fig. 8). A will be lower than B, and for this reason, that in A, there is nothing to back up the stream higher than E; whereas in B, it is backed up from D, causing a head of water there which is all employed in forcing itself and its sand down to E. The difference of level is only apparent when the stream has nearly reached its lowest point. Bandels arranged at C, before it has reached this, would aid in opening a channel, and be ready for the lowest state of the river when a current would set through it, and to assist which the bank at D should be shoaled up.

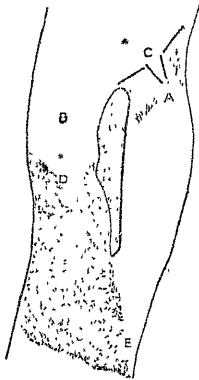



Fig. 8.

An immense quantity of sand is carried down by our Indian rivers, which travels along the bed, and is not taken into account when the sedimentary matters held in suspension are being determined; and yet, this is by far the more important of the two in forming shoals and sand banks along the course of a stream, and more particularly at its mouth. In a

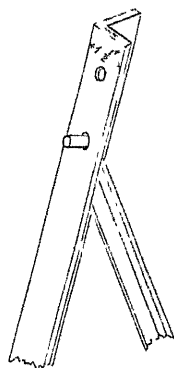
current flowing at five or six miles per hour the upper 6 inches of sand on the bottom is all "alive," and moving down very fast. Resistance to anything passing through it is scarcely greater than that of water. In the course of three days, I have seen a sand bank several miles long and half a mile broad, increased 3 feet in height, and this could only be a small part of the quantity carried down in the deeper part of the stream.

During the rains the bed is always relatively higher than in the dry season. This does not arise from the stream having greater breadth, and, consequently, less velocity; for the velocity is much greater as well as the stream being much broader. It must arise then, from the immense quantity of sand carried into its bed, and which with its increased velocity and breadth, is more than it can carry down for the time. The stream is literally overloaded, and at every favorable position we are sure to find immense deposits at these times.

On the subsidence of the river, the velocity and breadth decrease, and the depth goes on increasing, until in some cases, the bed is 6 or 8 feet lower than in the rains. This is very important in its bearing upon the navigtion of the Bhagurruttee. For, if the channel leading to it is not deepened steadily to keep pace with the deepening of the main stream, it is quite evident it must be dried up.

Improved Appliances.—I have already noticed the chief defect in the native bandel—its buoyancy. To remedy this, I would propose wrought-iron sheets instead of mats, retaining the bamboo piles and struts. The weight of the sheets would keep these in their position and prevent their being washed away. In addition to which, being impervious to water, their action would be more complete, and further would afford the means of cutting off a shallow current entirely, which is often very desirable, but with the old bandel quite impossible.

Fig. 9.

For deep water, I should propose a larger bandel made principally of iron, *see* Fig. 9, which shows the junction of the strut and pile, both made of angle iron; the facing might be of mats as usual. It would act very well and be quite sufficient for all the more important works on the Ganges; and the common bandel, when improved, as suggested, would be found amply sufficient for all works on its branches.

The expense could not be greater than the present system; as one line would be as effective as three ordinary ones, and though the first cost would be a little more, still in mats and bamboos there would be a great saving, without taking into consideration the immense amount of labor that would be saved, both in construction and in keeping down, or in attempting to keep down, the old style of bandel; and which, in spite of all precautions, causes great loss by being washed away.

Dredging on a limited scale would be of great assistance in opening a channel through shoals when bandels had already been constructed. For this purpose a steam dredge would not be required. A simple apparatus, to be worked by hand, is all that is necessary, and which might be easily rigged up. Something like Fig. 10, perhaps would answer; 5 or 6 feet is all it would have to work in, and that principally at the upper end of the channel, when the current being slacker there would be the most need for it.

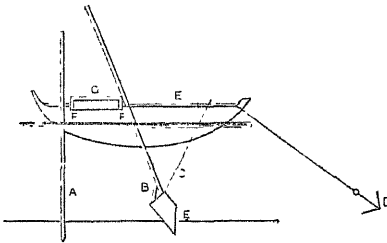



Fig. 10.

A—Pile for keeping boat steady.

B—Scoop.

C—Rope for raising scoop.

D—Anchor.

E—Platform on which to throw the stuff.

FF—Beams tying sides of boat.

G—Platform for men to work the scoops.

Raking up the sand, by drawing a "burrow" through it to be carried off by the stream, has been tried, but found not to answer. This would be very effective in clay, or clay and sand, but in sand alone, lying for some distance along a shallow channel, its action would be very limited.

With the view of obviating the necessity of keeping open the Bhagurruttee by costly works, it has been considered that a cut from the main stream into this branch would be far preferable, and secure at all times a sure passage for navigable purposes. A great deal may be urged against this plan. In the first place, it is not certain that the Ganges would continue to flow near its head, for one year even; and for many, it is pretty

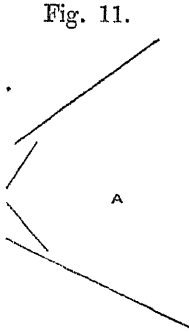
certain not to do so. In the next place, the cut must be very deep to allow the Ganges, when at its lowest, to flow through. And in the rains a heavy current would rush through, dividing the banks, making it in a very short time, in all its physical characteristics identical with a natural stream. If to avoid this action, locks were placed at its head, it would make no difference to the depth, as there would be no supply of water in the dry season higher than the bed of the Ganges. Besides, these works would be of a most expensive character and liable in any single year to be swept away or left embedded in a sand bank. Making such a cut therefore appears at best hazardous—it might remain open and be very serviceable, but for how long it is impossible to say;—but the chances are against it.

A plan was once proposed to let down immense iron pontoons into the bed of the Ganges for turning the stream down the Bhaguruttee, to be pumped dry and raised again when required. How would this answer? In the first place they must have a very large base, and be of immense weight to oppose the mighty current of the Ganges, otherwise they would be carried away like a ball. If anchored, they would become buried in sand, and although in the right place this year, they would not be next, and must be removed. If under the water, this would be a difficult operation; if on a dry sand bank, there would be the pumping, dry-digging away the sand, and hauling them to the water; requiring a set of apparatus nearly as costly as the pontoons themselves, and a large amount of labor. The plan is totally inapplicable to the circumstances—cumbersome and unwieldly in the extreme—as well as being most expensive in first cost and operation.

Works for Tidal Compartment.—I have not had the means of testing the suitability of the works already described, to the tidal compartment of our rivers; but I have no hesitation in saying, that they might be found most beneficial. Their simplicity, the ease with which they can be put down or taken up in the strongest current, would be found highly advantageous for the above purpose.

To meet the requirements of a double current it would be necessary to adopt some means to prevent the sand lodged behind the groin being carried back by the return current. This might be accomplished by having a double line of works (*see* Fig. 11). The facing of which, whether of mats or sheet iron, should be fastened down securely to prevent its rising with the

return current. There would be very little current at A, whichever way the current ran, and a constant accumulation of sand would go on here under the united action of both groins. The larger class of bandel described in page 34, I think would be lost. A trial on a small scale in a shallow part of the river, of the works already described, which surpassed my most sanguine expectations when tried in the Ganges, and the results of the trial carefully noted, might lead to a further and more complete plan for the final improvement of the Hoogly. I believe we have a system, truly an Indian one, which might, by further improvement, be developed into one peculiarly adapted for Indian rivers.

Fig. 11.

CAWNPORE,
August 24th, 1866.

W. H. L.

No. CXXXII.

PUBLIC WORKS IN BERAR.

By Henry Hooper Foord, A. Inst. C.E.

Berar, better known as the "Hyderabad Assigned Districts," is the northern portion of H. H. the Nizam's Dominions, assigned by the Nizam to the British Government as a guarantee for the regular payment of the Hyderabad Contingent, a force he is obliged to keep up in fulfilment of treaties. Berar has an area of 16,000 square miles, and is bounded on the north and east by the Central Provinces, on the west by Candeish, and south by the Nizam's Territories. It is divided into four Districts, under Deputy Commissioners, supervised by a Commissioner; he again is under the immediate orders of the Resident at Hyderabad. The great importance of Berar arises from the immense quantities of cotton grown in the districts generally, and in the valley of the Poorna in particular; during the American war, cotton reached prices that have enabled the cultivators to release themselves completely from the hands of the Sowkars, and to amass what, to them, have been large fortunes.

The geological character of the district is trap; this is found in the three stages of hard black basalt, decomposed basalt or moorum, and black soil. In the northern range of hills, known as the Satpoora hills, sandstone and lime-stone are found in considerable quantities; also to the south, in the Woon districts, near Oomrowutty, laterite can be obtained, but it is too decomposed to be utilized—crumbling away when exposed to the effects of the weather.

The rain-fall in Berar is very uncertain, averaging from 25 to 42

inches; this falls at intervals of about a fortnight; at times there is a heavy fall for three or four days, then a break of a fortnight, then another heavy fall. These periodical falls are called in Mahratta, Nuckshuttras.

Irrigation Works.—With the exception of damming up a small nullah at the village of Wangolee, near Ellichpoor, little or nothing has been done in the way of irrigation; the few old works originally built by the Mahrattahs, were allowed to fall into ruins long before the English Government took the districts under their charge, and since then, little or nothing has been done towards repairing the old works. Of Tanks there are none, with the exception of a few in Woon, and two or three in the Moorsee Talook, in the extreme east of the district; the soil is not suited for tanks, as it will not hold water, and no clay is procurable for puddling. A great amount of water could be collected and utilized by the building of Anicuts across the streams; many streams are already dammed year after year temporarily, by the villagers, and the water used for irrigation; as they are at the expense of these anicuts, no extra revenue is obtained. As to Drainage and Sewage there is none, but within the last few weeks, since the appointment of Major Nembhard as Commissioner, great activity has been displayed in improving the sanitary condition of the towns by surface drainage and the erection of latrines. The villages are collections of mud hovels with thatched roofs; no attention has been paid to laying out streets regularly; most villages are surrounded with the ruins of mud walls; these walls were built to protect the inhabitants against plunderers and dacoits. Of late years, owing to the better Government of the country, they have not been required, and have been allowed to fall into ruin, and should now be levelled so as to allow of the free circulation of air.

The commercial capital of Berar is Oomrowutty, situated six miles north of the Budnaira Railway Station; it is a large, walled, town; the walls, which are of masonry, are in an excellent state of repair; the houses of Sowkars and cotton merchants are large substantial buildings; the streets are very narrow; the want of air and drainage, the numerous cess-pools, the ruined houses used as latrines, cause altogether a collection of smells, that it is almost impossible to describe, and still more to imagine. The Commissioner is now opening out the town and improving the drainage. Khamgaum, in west Berar, is the second most important commercial mart. The third is Tirralah. Karunjah, formerly a wealthy and busy centre of

cotton traffic, has now lost all its importance, by the railway passing so far from it. The head quarters of all the departments is Akolah. The railway passes through the station, and Akolah is thus the best situated town that could have been chosen for the political capital of the Province. At Akolah, a large jail, court houses for the Commissioner and Deputy Commissioner, hospitals, schools, &c., have been built; a church will be built eventually. Ecclesiastical buildings appear to be put off to the last, there not being one place of Protestant worship in the whole district.

The Nagpoor extension of the G. I. P. Railway passes through Berar, traversing its whole length from west to east. With a view of placing the principal towns in communication with the railway, within the last few years, Government have devoted some funds for the formation of roads north and south from the railway. Of these six have been sanctioned as first class roads, and the remainder as fair weather roads; as yet only one has been completed, and that is from the railway station at Nandoora to Khamgaum, 12 miles in length; and even on this road the only two really large rivers have been left unbridged.

The first railway station on entering Berar is Mulkapoor, from this there are no roads, although the town is large and an Assistant Commissioner is permanently stationed there, and for whose accommodation a court house and residence, police and prison buildings are being erected; from the next station, Nandoora, a road, as mentioned above, has been completed to Khamgaum south of the railway, and another has been made to Julgaum north, the latter is a fair weather road, altogether impassable in the rains. The third station is Sheagaum; from here three fair weather roads have been made, two to the south to Khamgaum and Ballapoor, each 12 miles in length; and one to the north to Bawunbeer. The road from Sheagaum to Ballapoor is only crossed by one large nullah, and this even does not hinder traffic above an hour or two in floods; the large unbridged river, near Ballapoor on the Sheagaum and Ballapoor road, and the Poorna on the Shegaum and Bawunbeer road, offer very considerable hindrance to traffic; besides this, these two roads run over deep black soil, which becomes totally impassable for wheeled carriage throughout the rains. From the fourth railway station, Akolah, two roads are in course of construction, one north to Akote, 30 miles in length, and one south to Mallagaum, 40 miles in length. The former road is nearly complete; but on this, as on every other

road, the large rivers have been left unbridged, viz., the Poorna and Shanoor, and a length of about 3 miles between them. At Akote, and its immediate neighbourhood, the best cotton is grown. The Akote road has been metalled throughout with sand, and is now fit for wheel traffic at all seasons of the year, with the exception of the two rivers and the space between them. The Mallagaum road has been completely bridged, with the exception of six large rivers, and the earthwork has been completed—all work on it has been stopped for want of funds—when money is available it will be metalled with moorum (decomposed basalt) and sand; sand is a good covering to moorum roads; it prevents dust rising during the dry season; and in the monsoon, the water passes through it and it affords a dry footing for pedestrians. It is proposed to carry on this road eventually to Hingolee, a large military station in the Nizam's country, 8 miles from the boundary of the Hydrabad Assigned Districts—the extension will be 40 miles in length.

From Moortoogapoor, the fifth station, two roads have been sanctioned; one a fair weather road to Unjungaum, 40 miles in length; this has been completed, but here again the Poorna crosses the road and stops all traffic in rains; the road to the south has been completed as a metalled and bridged road, with the exception of two or three of the large bridges; which, however will be built, as the road has been sanctioned as a fully bridged road.

From Budnaira the most important station on the railway in Berar, two fair weather roads have been made to the south, each about 20 miles in length, to Salode and Karinjah; the two to the north have been sanctioned as first class thoroughly bridged and metalled roads; the first from Budnaira to Moorsee passing through Oomrowutty. From Budnaira to Oomrowutty, owing to the immense amount of traffic the road is being metalled with broken stone, and from Oomrowutty to Monsee with moorum and sand. The second road is to Ellichpoor; for the first 6 miles it takes the same line as the Budnaira and Oomrowutty road, and branches off at Oomrowutty, passing close to the walls of the town, and is continued on to Ellichpoor, a further distance of 30 miles; this road is important as connecting Ellichpoor, a military station with the railway, and is also the route to the hill Sanatarium of Chickuldah situated in the Sutpoora range. In the construction of the Ellichpoor road great difficulties had to be contended against in procuring material—stone was carted 20 miles,

water, three and four miles, sand for metalling, in some parts, seven miles. The average cost of the road per mile has been nearly Rs. 12,000. The Poorna, Peila, and Belgaum rivers are still unbridged, owing to the great estimated cost of bridges. The remainder of the road is bridged. Great credit is due to Mr. A. Izat, C. E., Assistant Engineer, in charge of the road, for the great skill evinced in its construction, and the indomitable perseverance and energy shown in overcoming the difficulties in procuring labor and materials. The Budnaira and Moorsee road has been many years in progress; the annual small grants prevent any works being done, or very little. No better example can be given of the draw back of annual small grants for a large work, than by comparing the progress of the Imperial Road between Budnaira and Moorsee with the railway—before the railway was completed to the Thulghat, this road was commenced; since then the Thulghat has been made, and some 350 miles of line completed to the east of it, and yet the Budnaira and Moorsee road is not completed, nor is there any chance of its being completed with the present small annual grants for another 10 years. This slow progress is no fault of the D. P. Works, but arises simply from the fact that only the surplus revenue of Berar is available for Public Works. Everything and everyone is first to be paid, and the balance given for Public Works.

The last station on the railway, within the limits of Berar, is Chandoor, from here, two fair weather roads have been completed, one north to Koora, 12 miles, and one south to Yeotmal, the head quarters of the Woon district; both roads are fair weather roads.

In addition to the above roads, the principal village tracks are annually repaired and improved by the Local Fund Engineers; but owing to the deep black soil of the country over which nearly all the roads pass, the greater part of the cart traffic is absolutely put a stop to for four or five months of each year. At several of the railway stations, dâk bungalows for Europeans, and serais for native travellers have been built; wells have also been excavated and trees planted with a view of forming encamping grounds. A few bungalows for the accommodation of travellers have been built on the principal roads, but many more are required. The public buildings in Berar are well built, and have a handsome appearance; the large Jail now in course of construction at Oomrowutty, under Captain Burton, R.E., is a good specimen of rubble work. Government were induced to allow this to be built pucka throughout—there

is no worse economy than building with mud in Berar—the bricks are vile, the clay for building is worse. After careful calculation and a lengthened experience in building kutcha, only one conclusion is arrived at, and that is that it costs more to plaster, point, and otherwise protect a kutcha building in Berar than to build it properly at first.

No labor is procurable in Berar, the scanty population of the Province find it more profitable to work in the fields than to work either for Government or any private company, so all labor has to be imported. The greater part of the skilled labor, such as bricklayers and brickmakers, stone masons, carpenters, tile-makers, and lime burners, come from Secunderabad. Coolies are procurable in all the villages in the Nizam's country. Some now employed in Berar, brought originally from the Nizam's country, have worked for the Department three years, with occasional leave of absence during the rains. Nearly, if not the whole of the work in Berar has been done by contract; the small native contractors generally require an immense amount of watching to prevent their scamping the work; they are also very troublesome in settling with finally, denying measurements, payments, and often their own written statements and signatures; every one of them declare they work at a loss, and yet after having indulged themselves in a great deal of perjury and false swearing, on the conclusion of one job, they after a little, importune for a fresh one. The hungry vakeels that throng the courts induce these men it is believed to file suits, the arrangement being to go halves in case of winning the case, and to receive the stated fee or percentage on amount claimed if they lose; the vakeel in either case makes something.

The establishment kept up for supervising the Public Works in Berar consists of two Executive Engineers, and two Assistants, four Assistant Overseers, and a small temporary establishment of Sub-overseers; the Superintending Engineer being also Secretary to the Resident at Hyderabad, is necessarily obliged to reside at Hyderabad, visiting Berar as often as possible. In addition to the Public Works' Engineers, in each of the four Districts there is either a Local Fund Engineer, or subordinate. These officers undertake the building of police stations, travellers' bungalows, serais, town improvements, and the improvements of village roads. The wants of Berar are *roads* and *irrigation works*, a larger Public Works Establishment, and a much larger annual grant; the savings from the revenue will not approximate for years to come to what should be expended. As

the works are emergent, a loan only will meet the difficulty; it is a fair and just method of paying for Public Works, for why should the present generation only, have to pay for works that will benefit posterity, even in a greater measure than it will them? A short time since, a Memo. was in course of being prepared, showing the cost of metalling and bridging all the roads reported as emergently necessary, and of the public buildings required for Civil officers, and of irrigation works that were certain to be highly remunerative—before one-half of the expenditure was calculated, it was discovered that the probable annual grants for the next quarter of a century would not suffice, so the list was destroyed after seeing the hopelessness of trying to concentrate the work of years in four or five, as no funds were available.

No. CXXXIII.

IRON SLEEPERS ON INDIAN RAILWAYS.

The very heavy cost of maintenance of way on some of the Indian lines, owing to the rapid deterioration of the wooden sleepers, having attracted the notice of Government, opinions were asked for from the Chief Engineers and other Officials of the several lines, as to the comparative merits of Iron and Timber sleepers, and the advisability of adopting the former in all future cases.

The only system of Iron Way which has been employed to any extent in India is Greaves', consisting, as is well known, of cast-iron hemispherical bowls, on which a chair of the usual form is cast; each pair of bowls being connected by a wrought-iron tie, by which the gauge is actually preserved.

The following is an abstract of the most important opinions obtained on the subject. Although there is some difference of opinion, the balance of facts seems to determine that for sand ballast, for not too heavy a traffic and for not too great a speed, Greaves' sleepers answer exceedingly well. When the ballast is of hard material, such as broken brick or kunkur, there appears to be danger of the bowls breaking, especially at high speeds. Appended will be found a description of a *Wrought-iron* Road which has been patented by Mr. Sibley, Chief Engineer, E. I. R. (Upper Section), and which has been tried to a small extent with apparently satisfactory results.—[Ed.]

From W. G. Smart, Esq., Chief Engineer, Madras Railway.

The South-West Line, 406 miles, was originally laid with country timber sleepers. It was very soon discovered that the deterioration of the wood was so rapid that, unless a more durable material were substitu-

ted, a very large sum would have to be expended annually on renewals, and iron sleepers were introduced on the portion east of the Cauvery *i. e.*, 241 miles. On the Western Division, where timber of a better quality is procurable at moderate prices, the use of wood has been continued.

The Bangalore Branch and the North-West Line were originally laid with iron sleepers. The former was opened for public traffic on the 1st August, 1864, and the first portion of the latter was opened in 1861.

For the purposes of comparison, it will be best to take the statements of the cost of maintaining the North-West Line and the 4th Division of the South-West Line, as one is altogether an iron road, and the other altogether timber, and both have been open for traffic about the same time. The average cost of the first has been Rs. 54 per mile per month, and of the latter Rs. 108. The 3rd Division, of which 36 miles are iron, and 59 wood, averages Rs. 88. The 1st and 2nd Divisions are still in a transition state; the balance of iron sleepers required to complete the iron road being on the first Division 12 per cent. of the total number, and on the second 30 per cent. This circumstance accounts for the higher cost of maintenance.

As regards the effect of the iron road on rolling-stock, I subjoin extracts from two letters from the Locomotive Superintendent of this line; in the first, dated 12th June, 1863, he says :—

"I cannot well send in any official report until engines have been running long enough on the North-West Line to show appreciably what the wear and tear is on the tyres; a report sent in at this early period of its existence would be of little value, and might mislead, because we have not had a sufficient number of engines working solely on that line to enable me to deduce from their wear, fair average results.

"My own views are, like yours, decidedly in favor of the iron pot-sleeper road; and, speaking generally, I believe that our stock has suffered far more from the wooden sleeper road than from the iron road, on account of the sleepers being many of them defective and badly packed. Where the pot-sleepers are well packed, and laterite or sound ballast is used, I have always found the engines and stock to run smoothly and without jarring, and from our entire freedom from accident on the latter road, I should prefer seeing them in use throughout the line.

"The North-West Line is, as a whole, in my opinion, a less injurious road to rolling-stock than the South-West Line, and the engines and

rolling-stock working on that line have required, if anything, less upholding than the stock generally on the South-West Line."

In a subsequent letter, Mr. Wright says:—

"No. 38 Engine ran 22,050 miles on the South-West Line, when she came in for repairs, and had her wheels turned up for the first time.

"When turned out of the shops, she was placed on the North-West Line, where she ran 27,348 miles, when she came into shed again, and had her wheels turned up.

"This result is in favor of the pot-sleeper road, more especially as engine wheels usually run a less number of miles after having been once turned up; the outer layer of metal generally being the most durable.

"It is, however, only fair to the wooden sleeper road to observe that, during the greater part of the time that No. 38 was running on the South West Line, the road between Madras and Vellore (where she ran) was, generally speaking, in very bad order."

Our rails on the North-West and Bangalore Line weigh 75 lbs. per yard. It is essential that the ballast should be of such a description as not to bind, and broken stones and coarse gravel should be carefully avoided. I find the best ballast to consist of a mixture of coarse sand and laterite gravel, or rotten granite, commonly called in this part of the country, moorum. Where the road is laid through rock cuttings and over bridges, I always use teak sleepers, as the iron requires a foundation possessing some degree of elasticity.

From the Deputy Chief Engineer, Permanent Way, to Chief Engineer, Madras Railway.—Dated 21st February, 1866.

Smoothness of road.—A road laid entirely with iron (on the Greaves' pot system) bears a very favorable comparison with one laid with good timber sleepers. It requires a smaller number of men per mile to make good "slacks" and unevenness of surface; and, if provided with a tie-bar to each pair of pots, is less liable to irregularities of gauge.

Wear and tear of rolling-stock.—Upon this subject, a reference must be made to the Locomotive Superintendent.

Proportionate number of breakages.—The number of breakages is exceedingly small. For instance, upon the first division of the South-West Line, over which there is a very heavy traffic, it amounted, during

the year 1865, to ·544 pots, upon a total laid in the road of 283,559. This is equivalent to about 0·191 per cent. Some months back, I made an examination of broken pots in the road, and I arrived at the conclusion, that a large proportion of the fractures were originally due to defective loading or unloading, and not to concussions from rolling-stock after the pots were laid down.

Renewals.—During the year 1865, the cost of maintenance upon the North-West Line (an iron road throughout), including the renewals of fractured pots, averaged Rs. 61-5-11 per mile per mensem.

Upon the fourth division of the South-West Line (a road laid entirely with timber sleepers), where there is less traffic than upon the North-West Line, it averaged Rs. 132-6-9 per mile per mensem. From these figures it will be seen that, upon a road laid with iron, a saving can be effected, comparing it with a wooden road, of 54 per cent. upon the cost of maintenance.

Frequency of accidents.—Before we laid down iron-sleepers upon the South-West Line, trains were on several occasions thrown off the rails, owing to the bursting out of the wooden road. Since iron has been so extensively employed, we have been altogether free from accidents of this nature. In my opinion, an iron road laid with Greaves' sleepers is perfectly safe for trains at the highest speeds.

Ballast and packing.—The best description of ballast is sand or sand and rotten granite (moorum). Laterite is objectionable, for the simple reason that it cakes during the dry season, and retains moisture in wet weather; in the first case causing a certain amount of rigidity tending to fracture the pots; and in the second, rendering it difficult to pack them and maintain an even surface. The packing is effected by means of a rammer or crow-bar, working through the two circular holes cast in the side of the pot.

From the Locomotive Superintendent, to Agent Madras Railway Company.—Dated 28th March, 1866.

With reference to your letter of 20th February, forwarding a printed Order of Government, having reference to the use of cast-iron pot-sleepers, I beg to inform you that, since their general introduction on this line, the wear and tear on engines and rolling-stock has been perceptibly

increased, the amount of injury being however, confined to the wear of tyres so far as it is appreciable.

On the opening of a portion of the North-West Line, where the pot road was particularly good, the results seemed at first very favorable, and we scarcely ever had a broken spring; whilst on the South-West Line they were continually breaking. This, however, was, no doubt, entirely due to the bad state of the wooden sleeper road between Madras and Vellore; and at that time the pot-sleeper road, judging from such limited statistics as I possessed, appeared to offer advantages as regards general wear and tear over the wooden sleeper road which then existed.

There can, however, be no question as to the superiority of the wooden sleeper road over the pot sleeper road as regards smooth running, both being alike equally well maintained; but the difficulty and expense of preserving and maintaining the wooden sleeper road in this country is so great, that, practically, I believe the pot-sleeper road to be on the whole the best and safest, and undoubtedly the cheapest description of road, and I think that these advantages will probably be found to outweigh the extra cost of repairs to rolling-stock.

I see no danger whatever in running trains at express speed, say at 50 miles an hour, upon a pot-sleeper road. Indeed, I have frequently run over it at this speed with special trains conveying His Excellency the Governor and others, and never experienced any indication that would lead to the supposition of its being an unsafe road for trains running at high speeds.

In those parts of the road where the ballast or material of which the road is formed, is of a yielding nature, there is little, if any, difference perceptible between it and the wooden sleeper road; but laterite, unless frequently opened up, is apt to cake and become very solid, in which case a harsh and unpleasant action is transmitted to the rolling-stock.

Upon the whole, however, the pot sleeper road appears to me to be particularly suitable for India.

From A. Shanks, Esq., Resident Engineer, Calcutta and S. E. Railway Company.—Dated 3rd February, 1866.

But few years having elapsed since the introduction of cast-iron sleepers

considerable difference of opinion exists as to the wisdom of bringing them into general use: for, no doubt, they possess bad qualities as well as advantages.

The short length of this line laid on pot-sleepers has not afforded me much opportunity of testing their merits or otherwise; ours are bedded in coarse sand; this being retained in position by a wall built on either side, the road is kept in order with little difficulty, and I find that, in running trains up to 45 miles per hour, the motion is smooth and agreeable, and I do not apprehend any danger from running at such a speed.

But it must be borne in mind that our sleepers are exceedingly strong, the pair weighing 210 pounds, (being, I understand, 75 per cent. *heavier* than those lately sent out for the East Indian Railway); they are, therefore, little liable to fracture; the first cost of them, as well as that of their carriage, is proportionally higher, and the retaining walls necessary in most localities raise their cost most materially over those of wood.

I am, therefore, of opinion that pot-sleepers of from 21 inches to 24 inches diameter, when made of *sufficient strength*, provided with good tie-bars, and *evenly packed* with sand or other *small* ballast, are safer and six-fold more durable than timber sleepers. The cost of the former will be nearly double that of the latter, and strict compliance with these conditions is most necessary to ensure success in their application on lines with heavy or fast traffic.

The life of a wooden sleeper, whether of creosoted pine, teak, or sál, cannot be reckoned at more than five or six years: I have found many of them perfectly rotten in much less time, and I doubt whether there are two opinions as to the danger to which traffic is exposed in being carried over them; their external appearance often leading one to suppose they are sound when they are really unsafe.

The subject of suitable sleepers for this climate has lately occupied a considerable share of my attention, and I am of opinion that much better results would be obtained from the use of *wrought-iron* transverse sleepers than any other yet tried: such a sleeper might be made 10 feet long and 10 inches broad, with its under side concave, the bearing area would thus be the same as that of the present wooden sleeper, their weight not more, and their strength much greater, while they would be five or six-fold more durable.

From reliable data, I find that such sleepers would only cost 25 to 30 per cent. more than those of wood, and the advantages which appear to

attach to such a size and shape should, certainly, warrant at least a trial of the principle.

Note by Chief Engineer, E. I. Railway, N. W. P., on the Greaves' Pot-sleepers used experimentally in the N. W. Provinces.—The Board having sent out 200,000 bowls (equal to 100,000 sleepers), it was determined that half should be used in Bengal, and half in the North Western Provinces.

Of these 100,000 bowls, 92,441 reached the Delhi District. The Store-keeper at Allahabad reported having 9,165 broken, or more or less damaged; he was directed to send forward all that would be serviceable for even temporary purposes; the result was the above number, of which 86,844 were put into the permanent road, chiefly between Khoorja and Dadree Stations.

Part was laid wholly with bowls, generally 7 pairs to the 20-feet rail; and part with timber sleepers on each side of the rail joint, and 5 pairs of bowls intermediately.

The former arrangement, though giving a little trouble at first from unequal yielding, is decidedly the best arrangement. The cross ties were at first placed only to each alternate pair of bowls, it was afterwards found necessary to put them to each pair.

The bowl road is laid wholly on kunkur ballast, and care was taken to have it broken fine for packing inside the bowls.

This length of road has, from the first, been the worst length on the Delhi District, and has taken much labor and expense to keep it in anything like travellable condition.

During the last six months, 1,410 bowls have been re-placed, but this does not at all represent the number actually broken, as, owing to the evils which arise from unequal packing, the opening of the road is deferred until it can be so no longer.

Any ballast that we can obtain, except hard clinker or stone (which would break the bowls), binds when broken and packed in the core; when a bowl is re-placed, if it be packed slightly higher than its neighbour, the latter receives a blow and breaks like a biscuit in the hollow of the hand.

With a sharp Thames sand or analogous ballast, which would give a firm bed without binding, this objection would be avoided.

Owing to the very unsatisfactory condition of the road, I had lately a

length of 345 feet of the road opened out and examined. Out of 210 bowls in the road, 90, or nearly 43 per cent. were broken, and in several cases, as many as 11 out of 14 under a pair of rails were broken.

In another portion of road subsequently examined, out of 150 bowls, no less then 79 are broken, more or less, and of these 64 are badly damaged. The ballast is kunkur, of average size and inclined to be soft. The bank is 5 feet high of good hard sandy loam. There are 5 pairs of bowls to each 23 feet rail, with timber sleepers at the joints.

The use of Greaves' pot-sleepers in the North Western Provinces must be regarded as resulting in decided failure.

I should add that most of the road has been under the charge of an Inspector who was on bowl roads in Madras.

In the correspondence forwarded from Bombay and Madras, it will be observed that the advocates of the bowl sleepers dwell less on the merits of the bowl sleepers than on the demerits of the timber sleepers. This course is no doubt admissible in discussing comparative merits; but as it is presumed that the object of this reference is rather to discover what is the best system of Permanent Way for India, it is well to note the above fact. All who have seen much of our cross sleeper road will be ready to admit the extremely unsatisfactory duration of all but the very first class of sleepers.

We have now a length in the Etawah District of inferior sleepers received from the Government Forest Agency, laid in 1861, of which nearly half have been renewed, and the majority of the remainder will probably have to be renewed within this year.

We have parts of the same district laid with first class sleepers 12 inches × 6 inches, of which scarcely any have been as yet renewed.

The avoidance of the evils attending the use of timber sleepers in this climate should not, in my opinion, lead to the use of cast-iron. Even were the behaviour of the pot-sleepers, when in the road, as comparatively satisfactory as it is decidedly the reverse, still the use of cast-iron would be most uneconomical as compared with wrought-iron.

This arises, first, from the heavy proportion which freight and subsequent land carriage bear to the original cost of imported iron; secondly, the greater weight of cast-iron necessary to obtain the same strength; and thirdly, the heavy per centage of fractures owing to the numerous transhipments and the fragile character of bowl sleepers.

It is to be noted also, that the fracture of one jaw of the chair attached to the bowl renders the whole useless.

From W. Bourne, Esq., Chief Engineer, to Agent, East Indian Railway Company.—Dated 1*st March*, 1866.

I deferred replying to your letter until I had received the Engineer's half-yearly Report upon the road laid with Greaves' patent bowl sleepers. The reports on the portion of the main line with these sleepers, for both the half-years ending June 1865 and December 1865, are unfavorable.

The facts upon which these reports were based are,—we laid a mile of experimental road at Undal, where our coal traffic is heavy; the road was carefully laid in and attended to. The result was that the breakage amounted to 7 per cent. per annum in the first half-year, and 7½ per cent. per annum in the second half-year; that the cost of maintenance in the first half-year was 50 per cent. in excess of that of the wooden sleeper road, and in the second half-year 46 per cent. A portion of the Singarrun Branch line, where the traffic is not so heavy as at Undal, is also laid with the bowl sleepers; the breakages have not been so numerous, and the cost for labor in maintaining not so much as upon the main line, in fact, less than that upon the wooden sleeper road.

Both lines are laid with the same permanent-way and ballast, and it appears from the above facts, that the bowls would favorably compete with the wooden sleeper road where the traffic was light and the speed slow, but on our main line, with our heavy engines, and long heavy coal trains, that they are not so well adapted as the wooden sleeper road for the traffic.

The ballast we have used is of broken bricks and broken sandstone.

From Chief Engineer, to Agent, Punjab Railway.—Dated 3*rd April*, 1866.

In reply to your letter of 3rd February, and enclosure from the Government of India, relative to the use of cast-iron pot-sleepers, I have to report that, on 70 miles of the line laid with these sleepers, from Mooltan towards Lahore, only 1,000 have been removed,* while, on the 4 miles at Sher Shah, no breakages have occurred.

The laying of the permanent-way with these sleepers was commenced in

* Does this include the number broken and left in the road.—[ED].

June 1863, and completed in August 1864, during which period material trains passed over it as the work proceeded, and since then, passengers, goods, and frequently ballast trains, have been running regularly.

The road was laid on the embankment, and earth used for boxing up; since then, for the greatest portion of the road, the earth has been cleared away nearly to the bottom of the pots, and the space filled in with broken bricks. The pots rest on, and are packed inside with, earth. The road is smooth and run over at the same speed as the sleeper road, and I am of opinion the wear and tear of rolling-stock is not greater than on a sleeper road, and that it is as free from accidents.

Mr. Nethersole, the District Engineer, reports :—" Both from personal knowledge, and from the experience of the plate-layers," I am of opinion that, " on the 70 miles of road laid on this district with iron pot-sleepers, the road will be (when boxing up is completed) equally as good for traffic as the wooden sleeper road; the trains run as smoothly over it, and it cannot, therefore, be considered a hard or rigid road." He further states, " several iron pots were put in originally slightly damaged, and owing to the rapidity with which the line was primarily linked in, many more were cracked; but, despite these disadvantages, I cannot find that 1,000 have been removed out of the 70 miles."

I may further mention, that only 1,985 sleepers have been broken in transit from Sher Shah during the construction of the line, including those taken out since the line was first laid.

From nearly eight years' experience of their use on the Egyptain Railway, between Alexandria and Cairo, I am of opinion, that with suitable ballast a good and smooth road may be maintained; and for the Delhi Railway, I propose bedding and packing the sleepers with sand, and covering the whole up with a top-dressing of kunkur or broken brick.

From Captain Sherard Osborn, R.N., Agent, Great Indian Peninsula Railway Company.

With the consent of the Directors of the Great Indian Peninsula Railway Company, I spent the interval between a mail for Bombay passing through Egypt, to collect the following information on the result of the long experience of the Railway Officials, in that country, of the efficiency and working of a line laid entirely on iron pot-sleepers, instead of the ordinary

wooden sleeper used in British India, and the following Memorandum is an abstract of a mass of notes made on the subject.

Mr. Hardcastle, Mr. Perry, and Abul Meyd Effendi, Civil Engineers in charge of different Sections of the Railway, all concurred in saying that, after eleven years' experience, the pot-sleeper, invented by Mr. Stephenson, appears equally well calculated for sandy soil, the rich black loam of the valley of the Nile (very similar to the black soil of India), or the hard unyielding surface of the country and cuttings between Cairo and Suez.

A large proportion of the pot sleepers introduced by Mr. Stephenson, some fourteen years ago, are still in excellent condition, and it appears to me that they were of a better quality than those more recently introduced into Egypt, so far as the quality of the iron was concerned, although there is no doubt that the form and shape have improved.

Edington's, of Glasgow, sleeper (pattern 1865) has a longer bearing for the rail on the crown of the sleeper, and the pot-sleeper itself is somewhat thicker in the crown than in the old pattern. This appears to be a considerable improvement; whilst Messrs. Greaves' patent pot-sleeper, from its larger area, was, in the opinion of one of the most experienced Permanent-Way Inspectors, admirably adapted for rock-cuttings, or in places where the pot-sleeper was liable to work down through the ballast to a hard unyielding surface.

But irrespective of the form of the pot-sleeper, it was very evident to me that as much depended upon the quality of the iron of which the sleeper is constructed, as the character of the wood does in a wooden sleeper.

The rule throughout the Egyptain Railway is to have seven pairs of pot-sleepers to every rail, and they average twenty-one feet in length. Of these seven pairs, four pairs are tied with iron tie-bars, and experience has shown that it is by no means advantageous to tie together a greater proportion of pot-sleepers, whether it be on curves or inclines however sharp, or however steep. The reason for this may be easily understood, when it is remembered that the great point with a permanent-way must be to preserve the gauge without destroying the necessary lateral elasticity of the road. I observed two curves of eight chains each near Cairo; the ordinary working curves on the line are twenty chains.

I allude to this point of leaving a certain number of pot-sleepers untied in every rail, because the Egyptian experience is at variance with the

opinion of the Chief Engineer of the Madras Railway in his Report, he being in favor of tying every pair of pot-sleepers in curves and on inclines.

The packing or *punning* of the pot-sleepers appears to be an important though simple measure in insuring the satisfactory construction of a permanent-way. The sleeper in all cases requires to have two holes: those with one hole only are now obsolete. Through these holes, the earth, or small ballast, is poured and rammed gently, until the interior of the sleeper is quite filled. It appears by no means desirable to ram the contents of the sleeper so as to destroy the elasticity of the road. In rock-cuttings and on hard surfaces, the pot-sleeper requires about fifteen inches of ballast to be spread before the sleeper is laid down. This will ensure the pot, if it is subsequently properly filled, not working its way down to the rock; but I may mention that, in more places than one, I observed the edge of the sleeper quite down to the hard unyielding surface, without any injury appearing to occur to it—the interior of the pot-sleeper was, of course in all such cases well packed with ballast.

At one point, near Lake Mareotis, where the line had become perfectly rigid, and had formed from the amalgamation of lime, and sand, and iron, a hard conglomerate, the sleepers did appear to break in a great proportion than elsewhere; the remedy for this was simply lifting the sleeper and relieving it, so as to restore the necessary elasticity to the road; the rolling-stock, however, did not appear to suffer there more than elsewhere on the line.

On rocky surfaces, as well as where there is much lime in the soil, and the iron is disposed to bind with it, it is always best to lift the pots slightly at intervals of time so as to insure due elasticity. If this is done, they will stand for a long period. On earth banks which have consolidated, or on sand, the pot-sleepers require but little expenditure of labor, and I was informed that, with a road once in good order, one-half per cent. per annum was the average repairs of pot-sleepers.

In the main line Station of Alexandria, where there is a good deal of heavy shunting constantly going on, I was shown iron sleepers that had been down eight years, and were as good as ever.

The maintenance of the permanent-way in Egypt is in cost a mere bagatelle to that of the Indian Railways, and is carried on by a body of old soldiers who have gone through the first period of Military Service, under

the control of an old Officer. These are paid from the Railway Revenue, and instructed by the Railway Engineers.

I was told that the proportion of the Plate-layers to every five miles of road was sufficient to maintain a single line of rails after the road was once in good order. The condition of the permanent-way appeared to me to be better than the major portion of our own Railway.

From George Betts Bey, the Agent and General Superintendent of the Viceroy, as well as from the Locomotive Superintendent, I learned that they were both convinced of the superiority of an iron permanent-way over a wooden one in every respect. The Locomotive Superintendent allowed that he had been at first, like most people, prejudiced against the pot-sleeper, from an idea that its non-elasticity would injure the rolling-stock material; but both these gentlemen were convinced that the perfection of the gauge, the ease with which the road was maintained in a country where skilled labor was quite as difficult to be obtained as in India, and the safety with which, at a great speed, heavy weights were carried by Native Drivers over such a road, placed the iron permanent-way far before wooden sleepers for all Railway purposes in Eastern countries.

I was assured by all Departments that, except in collisions, the case of an engine or train running off the rails was almost unknown in Egypt, although the Drivers, even more than in India, constantly make up time by running at a reckless speed. The only explanation that could be given of this was the fact that, unless the tie-bars carry away, the road with iron pot-sleepers must always be in gauge.

I need not point out how much this is at variance with our own experience on our Indian Railways. Here trains have frequently run off, and life has been either lost or endangered, without any assignable cause. Our Permanent-way Inspectors generally declare the road laid on wooden sleepers to have been in gauge when it is very certain that it could not have been so, or the engine would not have run off.

The Alexandria express train now travels at the rate of forty miles per hour, and the road is considered safe for the speed of a mile a minute. Indeed, I was assured on pretty good authority, that the express in making up time often attained that, or a higher rate. The goods trains on the Egyptian Railway are, I suppose, the heaviest that have ever been worked on so light a permanent-way, the majority of the rails being only sixty-five pounds per yard.

Their goods engines are very large and powerful ones, some of the French engines being nearly as heavy as our Ghât Locomotives. The goods trains often comprise from forty to fifty wagons, averaging eleven tons gross weight when loaded,* and the speed ranges from twenty to forty miles per hour.

I quote this to show how severely the Egyptain line has been tested, and not at all with view of urging such a system on Indian Railways.

On Mr. Perry's section of the line I found they were taking up twenty-two miles of rails laid upon wooden sleepers, and re-placing them with iron ones. This was done to insure *the road being capable af carrying the traffic with safety, and to reduce the expense of maintenance.*

I found that wooden sleepers could have been imported from Dalmatia, Greece, or Turkey, at less cost than the iron sleepers from England, but that it was found in Egypt, as we find in India, that the wood simply decayed away when covered in earth, and subjected to the variations of temperature, and alternations of dry and wet soil.

Looking at the pot-sleeper as applied in Egypt, and comparing the road with the appearance of much of our line upon embankments in India, I am inclined to think that the thin iron tie-rod, instead of the heavy wooden transverse cross-beam, is much the surest way of preserving the gauge in countries where the maintenance of the line will always be carelessly carried out as compared with European Railways. For instance, on many of our embankments, it requires, no very critical eye to observe that the ballast is too high in the centre, owing to the constant washing away and subsidence of the embankment at the side where the chair and rail rests, and that consequently, when a train is passing over our roads in the wet season, the centre of the bank, and, of course, the centre of the wooden sleeper, becomes the fulcrum upon which the weight of the train is thrown, instead of resting as it should do, on the side of the bank along the line of rail.

Last year, between Julgaum and Mussawad, I saw a considerable length of line in this condition, leading, of course to an accident in which two or three hundred yards of sleepers were broken up, whilst the Assistant

* Engine and tender, tons, ...	50
45 wagons × 11 tons, ...	495
Total tons ...	545

Engineer and Permanent-way Inspector were ready to aver that the road was in excellent gauge, and so it was, so long as the weight of the train was not thrown upon it.

With iron tie-rods this could hardly ever occur, as they would easily cut down through the bank and preserve their position with respect to the pot sleepers, as the latter were forced down by the weight of the train.

One of the most serious objections that I have heard advanced against the pot-sleepers is the statement that, in the event of any accident, the loss of sleepers and chairs would be greater than with the ordinary wooden permanent-way. Some enquiries I made on this head lead me strongly to doubt whether this objection holds good in practice, and there are at any rate two classes of accidents to which we are liable with wooden sleepers that are totally unknown with iron permanent way.

The first I have already alluded to, that of the breaking of the wooden sleeper, owing to the centre of the bank being too high, and defective packing under the rail. The second is from the ignition of the wooden sleeper in the dry hot season, either owing to the hot ashes falling on them from the engines, or from trains catching fire when collisions occur or sparks fall on the goods.

Our losses from the burning of sleepers attributable to the second of these causes, have been very considerable. Looking therefore, at the question of iron *versus* wooden sleepers, in all its bearings, I am perfectly convinced, in the interest of the Shareholders, as well as the Indian Government, that the sooner Railways in the East are constructed of iron permanent way, the better. The losses to which this Railway has been subjected would be very difficult to estimate, especially in teak sleepers, and all the jungle-wood ones have proved to be utter failures, entailing enormous expense in renewals even before the roads have been opened to public traffic. The majority of the jungle-wood sleepers simply decayed away to dust within eight months, or within a year of being laid down. The teak last better; but every person, from the Sleeper Contractor to the coolies employed on the line, have made their profit out of them at the Company's cost.

The quantity of teak misappropriated and deficient within my own experience, has been something startling, and there can be no remedy for it so long as the wood is so precious and in such constant demand; for every bit of teak represents a certain monied value. It has been nothing

unusual in former days for a truck-load of teak sleepers to be missing and the sale of sleepers supposed to be used on the line for repairs is still very prevalent.

Now, with an iron sleeper, we have very little risk of robbery or misappropriation, the metal, even when broken up, being of no use to the natives; whereas, with a proper foundry capable of re-casting sleepers, such as every Indian Railway should possess, it will be very easy to carry the broken iron, and re-cast our sleepers; the tie-rod, in nine cases out of ten, merely requiring straightening.

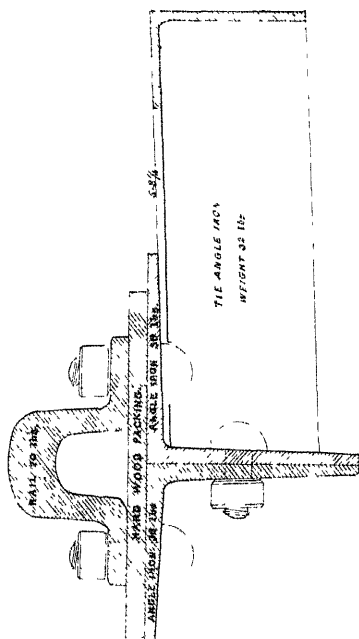
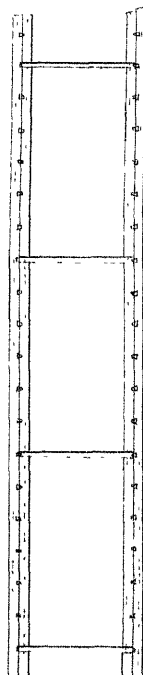
Looking to the future, moreover, I see no prospect of the teak forests of India being capable of maintaining the necessary supply for either the construction or maintenance of Indian Railways.

In the tenders sent in last year to an advertisement for teak sleepers, the prices ranged from Rs. 6-8 to Rs. 12-8 per sleeper, delivered in ships at Bombay, and not including landing charges or haulage. All the teak sleepers procured in this country of late for our Railway, are young trees sawn in two half rounds, which cannot be turned, and in many places not 3½ inches through. I have, of course, closed all such contracts. The Singapoor teak sleepers are of good proportions, cut out of the solid timber, but they are costly, and, apart from haulage, stand the Company in at the rate of Rs. 5-2 per sleeper.

I am aware that certain Officers of the Forest Department in India think we should give the jungle-woods another trial, and say that, with proper seasoning, many of them would last. I utterly differ from them, for many of our eyne and babool sleepers were years seasoning before they were put into the ground, yet, sound as they appeared on being placed on the road, they decayed away, I am told, in eight or nine months.

Note on Mr. Sibley's Wrought-iron Longitudinal Road.

Shortly after assuming charge of the works in these Provinces, my attention was attracted by the difficulty in obtaining sleepers, and the very defective character of many that had been supplied, and also by the defects in our fastenings, to the question of doing away altogether with so perishable and uncertain a substance as timber in this climate is.

On the 13th June 1860, I sent in designs for a wrought-iron road consisting of a lower continuous bearing, formed by two angle-irons 5½ × 5½ in 20 feet length bolted together, breaking joint at half the length,

and carrying a bridge rail bolted to the angle-iron longitudinals with $\frac{1}{2}$ inch hard wood packing intervening. The cross transoms or ties being placed at 10 feet intervals, also formed of angle-iron, and bevilled at the end to give the necessary tilt to the rail.

The Agent, on 27th June, 1861, recommended that five miles should be sent out, and the Government of India sanctioned this on 21st August 1861.

The first portion of this reached Allahabad in February 1864, but only enough to lay $1\frac{1}{2}$ miles were delivered before the road was laid into Delhi temporary Terminus on 30th June, 1864.

A further portion, two miles over the Jumna bridge and viaduct, and up to the Jail Road Bridge was laid, and has been run over since the Jumna bridge was opened to the public on 15th June last.

The length in Allahabad yard is 1,000 feet only, which was completed on 18th May, 1865, and all trains ran over it till the opening of the Jumna bridge, since when only the Fort Branch trains have run over until a few days ago.

The plate-layer informed me this morning that, after it was finished, it cost not more than half the labor of the other road to maintain, and for the last two months nothing has been done to it. The length over the Jumna bridge stands admirably over the girders, the angle-irons, instead of being supported on ballast, rest on sleepers laid longitudinally.

The length from the Jumna bridge to the Allahabad Station yard was laid chiefly on new high bank during the last rains. The bank beds yielded, but the road has been kept in very good order, though, of course, not with so good a top as it will have when the bank ceases to subside.

The $1\frac{1}{2}$ mile laid between Ghazeeabad and Dehli, about 4 miles from the latter, has been laid and run over for more than a year and a half, stands exceedingly well, forms a very smooth road, and is remarkably free from noise.

The advantages of this road are *first*, that it contains no perishable parts except the hard wood packing, a trifle in itself, which can be re-placed without disturbing the road.

Secondly, its great strength and stiffness, forming as it does a beam 9 inches deep, and 11 inches broad.

Thirdly, its great hold of the ballast, the central web being $5\frac{1}{2}$ inches deep, which keeps it firmly in line even in curves.

Fourthly, the facility afforded for packing without opening out the road as is necessary with the sleeper road; and

Fifthly, the diminished depth of ballast required, owing to the bearing surface being only 3 inches below rails.*

When I first drew out the design in 1860, the comparative estimate showed an excess cost at Allahabad, as compared with the ordinary cross sleeper road, of £158 per mile. In that estimate, sleepers were taken at Rs. 4 each, and carriage from Calcutta to Allahabad at £3 per ton.

Since that date, the price of sleepers has risen, and first class sleepers are now Rs. 5.

I append statement of present comparative cost, taking sleepers at Rs. 5, and carriage from Calcutta to Allahabad at Rs. 18 per ton,—our present rates.

This shows that at late rates the wrought-iron road is in Calcutta absolutely cheaper than the cross sleeper road by £93 per mile, and that at Allahabad it exceeds the cross sleeper road by only £34 per mile—a practical equality.

The alterations I now propose from that sent out are trifling—

1st.—I had intended, but did not sufficiently clearly specify, that the elliptical bolt-holes for expansion should be in the rails, and that holes in the top table of the angle-iron should be punched heart-shaped with a shank on the bolt to prevent turning while tightening up; they were sent out with round holes in rails, and elliptical in angle-irons.

2nd.—I have found it advisable to rivet instead of bolting the angle-irons.

3rd.—I propose to slightly deepen the cross-ties, leaving the breadth as at present.

I strongly advise that all future permanent way material got out for doubling the line in the North Western Provinces be of this design.

* The consideration which determines the full depth of ballast required is the thickness provided below the bearing surface; this is fixed on our line at 14 inches in the sleeper road: the bearing surface is 13 inches below surface of rails, and the ballast is boxed up to within 3 inches of rail surface (giving a total depth of 2 feet), to preserve the sleepers from exposure, and to secure the road from lateral motion.

In the wrought-iron road, the bearing surface is only 4 inches (instead of 13 inches as in a sleeper road) below surface of rails, thus effecting a clear saving of 9 inches, leaving the same depth below bearing surface.

The stability from lateral motion in the wrought-iron road is effectually secured by the deep angle-irons which have a 6-inch hold in the ballast.

Comparative estimate of Wrought-iron road and Cross Sleeper road.

Quantities.		Description of Material.	Rate.	Amount.	Total.
		Sleeper Road.	£ s. d.	£ s. d	£ s. d.
115	Tons.	Rails, 73 lbs., ...	7 10 0	862 10 0	
35	„	Chairs, ...	4 0 0	140 0 0	
5	„	Fish-plates, ...	8 0 0	40 0 0	
1¼	„	„ bolts, ...	20 0 0	25 0 0	
3	„	Spikes, ...	11 10 0	34 10 0	
3,200	No.	Keys, per 1,000, ...	5 5 0	16 16 0	
				1,118 16 0	
160	Tons.	Carriage to Calcutta, ...	2 0 0	320 0 0	
				1,438 16 0	
1,600	No.	Sleepers, ...	0 10 0	800 0 0	
		Total cost in Calcutta, ...		2,238 16 0	
160	Tons.	Carriage to Allahabad (excluding sleepers), ...	1 16 0	288 0 0	
					2,526 16 0
		Wrought-iron Road.			
110	Tons.	Rails, 70 lbs., ...	7 10 0	825 0 0	
110	„	Angle-iron, 70 lbs., ...	8 0 0	880 0 0	
7	„	Tie-bars, ...	9 0 0	63 0 0	
4	„	Bolts and rivets, ...	20 0 0	80 0 0	
				1,848 0 0	
231	Tons.	Carriage to Calcutta, ...	2 0 0	462 0 0	
330	c. ft.	Hard-wood packing, ...	0 6 0	99 0 0	
				2,409 0 0	
		Deduct 9 inches depth of ballast road = 66,000 cubic feet ...	0 8 0	264 0 0	
		Total cost in Calcutta, ...		2,145 0 0	
231	Tons.	Carriage to Allahabad, ...	1 16 0	415 16 0	
					2,560 16 0

In a subsequent note to the Editor, Mr. Sibley remarks :—

There is no analogy between the conditions obtaining in Egypt and those affecting our lines in Bengal. Egypt is practically a rainless country, where one half of the road is laid without ballast, in the alluvium of the Delta, and the other half on the fine gravel of the deserts.

The first course is impracticable in a country with tropical rains, and n this country (Bengal) we have no ballast at all resembling desert

gravel. Had we ballast similar to sharp Thames sand; so clear as not to bind and so heavy as not to be washed out by the rains, our bowl road would no doubt show a different result.

The Mooltan line runs through a country of exceedingly light rain-fall, and carries a traffic of something less than £9 per mile per week; for such a line bowls may stand, but you will observe that though they give the number taken out of the road, they do not state that they have counted the number of broken ones in the road.

Our bowls weigh 26 to the ton, and cost in England £4 per ton; freight, &c., £2; cost in Calcutta, £6 per ton; cost of a pair—

One-thirteenth of Rs. 66 = ...	5	1	3
Add 5 per cent for breakage, ...	0	4	0
Tie bars $\frac{1100}{1600}$, ...	0	11	0
	6	0	3
Deduct cost in Calcutta $\frac{1}{48}$ of a ton at 66, 2 chairs, .	1	6	0
4 spikes, .	0	6	0
2 keys, .	0	2	0
Total, .	1	14	0
Balance,	4	2	3

Ours you will observe weigh only 160 lbs. the pair, the Calcutta and S. E. weigh 210; so that the pair cost them about Rs. 5-4.

The only general concord of opinions is that the road should be an iron one; of the superiority of wrought-iron over cast-iron for a country like India, where the cost of carriage forms so large a portion of ultimate cost, there can to my mind be no possible question.

The only question remaining is the form of wrought-iron road. Of course I may be blinded to the defects of my own invention, but I believe it to be the best yet devised. I understand that Mr. Power considers it too light; it is not stated how; but seeing that it is vertically, much stronger, and laterally 10 times stronger than the double-headed rail, I do not think much of that objection. The only objection that the plate-layers make to it is, that it is difficult to "slue" over; this, though an objection during the first year, when the new banks are settling out of line, is an advantage for ever afterwards; the same qualities, lateral stiffness, and hold of the ballast, preventing its getting out of line.

No. CXXXIV.

FLOODS ON THE EAST INDIAN RAILWAY.

From W. D. Latimer, Esq., District Engineer, to Chief Engineer. —Dated 18*th August*, 1866.

In compliance with your letter calling for information respecting the nature of bridge foundations, and generally as to the effect of the flood of the 1st July last, on the bridges and works of the district, I beg leave to submit the following Memoranda.

On the night of the 30th June, heavy rain set in about 10 o'clock, and continued throughout the night without intermission. The downpour was so incessant, that I was prepared to hear of heavy floods next morning. I was, however, startled to find the low country completely under water: and in the station the water was running between the platform walls in a deep and rapid current, the water being as high as the horn plates of the carriages of the Up-Mail Train when it passed at 4 o'clock on the morning of the 1st July.

Whilst waiting for an engine to be got ready, I received a telegram from the Permanent-Way Inspector at Ahmoodpoor, informing me of a part of the bank near the down distant signal having sunk: in the same telegram he mentioned that the Buckasore Nullah was bank high, as it would be in an ordinary flood.

1*st July.*—The engine with material train being got ready, I left to make an inspection of the line and works, before any traffic trains could pass over, the Station Masters being warned that trains were to be detained until advised by me.

The first place where I felt any reason to be alarmed for a bridge

was at the $129\frac{1}{2}$ mile;—a small bridge of three 12-feet openings between the Garmorah bridge of three 60 feet spans (girder), and the Chilla of three spans of 60 feet; the small bridge being nearly midway between, is built in lower ground than the larger ones, and there was, in consequence an undue pressure upon it, so much so that I really feared it could not withstand very long, certainly not at the highest water; but, as the flood was then falling rapidly, I had hopes that nothing serious would result.

The next place where the flood was above ordinary height was at the Dwarka, where it had risen higher than any record of it since 1862. On this occasion it was 6 feet higher, at the same time passing off both in the main channel, and through the auxiliary flood openings, without apparently any great risk to the works.

The next place where an extraordinary heavy flood was running was at the Mooneecandour bridge, where there has not been even what might be considered an ordinary discharge of water since that recorded by Mr. Perry when the works were in progress in 1855, when Mr. Perry wisely proposed having the embankment raised, and the intended water-way increased.

Again, at the bridges between the Mooneecandour and the canal, the flood was unusually high, but not sufficiently so at the bridges to cause any alarm for their safety; nor at that of the canal bridge where it was discharging with a considerable head without any apparent risk.

At the More bridge the flood was excessively high; the head of water was fully 4 feet on the cut-waters, and more at the double piers, but there was no injury being done, and nothing on Sunday, the 1st, to cause me any fear for the bridge or works.

On my way down I had a message saying something had gone wrong at Buckasore bridge. On reaching the place I found the parapet and No. 4 pier from south abutment had sunk, showing a depression of $5\frac{1}{2}$ inches on the east side only; the other portions of the bridge being to all appearance sound and secure. The No. 7 Up-Passenger Train was then due; but, in consequence of the flood, it was stopped on the south side and sent back to Burdwan. The bank behind the south abutment was at the time cutting; but as the flood had subsided some 3 feet, I was of opinion it had done its worst, and, after waiting to a late hour, I left the place to again examine the bridges I have remarked upon as

being surcharged, and to make enquires and examine the bridges north of Rampoor Haut.

Before I had returned many hours to Rampoor Haut, I had a message that the west side of Buckasore bridge had fallen over. On that side there was no apparent failure whatever up to the time I left it late on Sunday afternoon.

2nd July.—On Monday morning, the 2nd July, having ascertained there was nothing to fear north of Rampoor haut, I resumed my examination of the bridges south, where I was accompanined by Mr. Sibley, who was *en route* to Calcutta by Sunday's train.

The telegraphic communication was interrupted between Rampoor and Cynthea. On our way down, we supported and put the wires right at several places where they had given way. At the River More the flood was still within about 4 feet of its highest; and although there had been a tendency to cut the embankment behind the northern abutment, it had apparently ceased: the stream returning from below the bridge, through the 1st and 2nd arches north, set in an opposite direction away from the Railway embankment in such a course as not to excite any fears for the result.

On proceeding downwards to Ahmoodpoor, the water had gone down in all the streams, leaving only slight traces of injury at some of the bridges. At the 112th mile a bridge of four 15-feet spans had the protective brick flooring washed away, as also some earth from the wing-walls.

On reaching the Buckasore, it was in the state I had been advised by telegram; the greater part of the west half of the bridge having fallen over entirely, or inclined to the up-stream side. A breach of 125 feet was made through the embankment, 15 feet in height, behind the south abutment, and the river bank at the place was scoured out to a depth of 33 feet below surface of ground, or 48 feet below rail level. The rails across the breach were suspended in mid-air with the sleepers attached: the communication was entirely cut off, except by that means. In order to make it passable I sent the train back to Rampoor Haut for a supply of planking and material required to get the Bombay Express Mail forwarded. The train on going back found the flood at the More had risen some 5 feet from the time I had passed down in the morning; the direction of the current had entirely changed: setting

against the northern bank, it cut away and scoured out in the course of two or three hours, the natural bank of the river on both sides of the Railway; the whole volume of flood water then passing through the side cuttings, and overflowing the face of the country, until it found a vent through the canal and other bridges between the River More and Mooneecandour bridge of forty-five 15-feet openings, $1\frac{3}{4}$ miles distant from the More bridge, and at right angles to its natural course.

The embankment, 25 feet in height, behind the north abutment of the More bridge, was cut under the rails for a length of 105 feet; the rails and sleepers left hanging as described at the Buckasore bridge. At the More, the embankment was only cut through three-fourths of its width, with an additional length of 200 feet of cess and slope washed away.

The engine and train returning to Rampoor Haut got over the bridge and the embankment before it was breached, but unfortunately it could not get back again: and, in consequence of the Copai bridge about the same time showing indications of failure, we were left without engine power between the $101\frac{1}{2}$ miles and the 119th mile,—a distance of $17\frac{1}{2}$ miles: the only means of communication over the length was by trolly, by which conveyance the mails were forwarded.

The flood water at the More, Buckasore, and Copai rivers kept at such a height on Tuesday the 3rd, as to seriously interfere with any work towards repairing the heavy damage at the bridges: the first attempt was made at the river More, where it was an object to get an engine over the bridge to re-open the communication as far as the Buckasore, a distance of 11 miles. In consequence of the height of the water, earth-work was of no avail on the first day: the bottom and deep scour had first to be filled with heavy stone and masses of brick-work; the former was only obtainable at Koolapahar and Seetapahar, 71 miles distant. All available labor, with as many trains as engine power could be supplied for were engaged in leading and bringing material for filling in the breach. The distance and consequent delay in getting material to the place was equal to a day's loss of time. On Wednesday, the underseat of the embankment was sufficiently advanced with ballast filling to admit of earth filling being used. The embankment was in consequence made to its full height, and wide enough on the

evening of Wednesday, the 4th, to pass an engine with a loaded train of ballast over the breach at 8 o'clock P.M.

This difficulty being passed, reduced the interruption to engine traffic to 6¼ miles, with the additional advantage of being able to lead stone and material to Buckasore bridge, where no earthwork could be done in the breach and stream, without first checking its force by a barrier of stone and heavy ballast.

5th July.—On Thursday, the 5th, the flood-water had considerably subsided; and, with the aid of stone, as before-mentioned, the current was sufficiently controlled to admit of an attempt being made to stop the breach by earth filling, at which over 2,500 coolies were employed.

The work of making a new road over the east side or half of the bridge left standing was at the same time being carried out:—the ballast was all removed, first to allow of clay puddling being introduced over the crowns of the arches; brick spandril walls being built to support the strong framing of longitudinal balk timbers being laid over the bridge to which the cross sleepers are bolted, the rails and road being thus continuously supported.

On and from the 4th, the passenger carriages were hand-shunted by coolies over the length between Copai and Buckasore, where they changed trains. The work at the bridge and breach in the embankment was continued; the traffic being worked as described up to Tuesday, the 9th, when the down-train was pushed over the new road made over the east side of the Buckasore bridge, and the breach in the embankment filled in. After which the engine was taken over, following up the hand-shunted train in its slow progress; in a short distance it was overtaken and pushed on to the Copai bridge. The engine being kept between the two bridges, for which sidings were put in at each place, the great delay to traffic was thus overcome on the 9th, when the up and down-trains were passed over the bridges with only a delay at each place in hand-shunting of from 10 to 15 minutes.

On the morning of the 10th, a second engine was taken over Buckasore bridge, and on the 11th, a third one was brought over to re-place the first one, a passenger engine, considered too light for goods traffic.

From that date (the 11th) the goods traffic might have been resumed over the entire district, and worked as it has been since the 15th

without any delay or interruption to the ordinary traffic trains, as has been since proved by extra trains being passed on the first two or three days, to clear off coal and other trains detained at stations on the 1st of July.

Similar work to that described at Buckasore was being carried on at Copai, where a new road was laid on timber framing, by which the traffic will be carried over on the east side of the bridge.

When that work is completed, and the arches are supported by centres, as is being done both at Copai and Buckasore, the engines and traffic will work over both of them as heretofore. The work of bringing stone and ballast to Copai was undertaken by Mr. Cockburn: the communication being cut off from the north, no material could be sent to it from this side.

In giving an opinion on the course of the disaster at Copai and Buckasore bridges, there can be no question as to the extraordinary height of the late flood and its sudden rise. We have evidence of the height being greater than any flood since 1833 in the district westward of the Railway. At the Railway itself, the only record we have of any flood approaching the last one is that of 1862, when the water was at the Buckasore bridge as follows:—

Up-stream side from rail level	9·25
Down ditto ditto	11·25
Showing a head of	2·00

In the late flood, the surface of water above bridge was—

Below rail level	4·09
Below bridge from rail level	9·34
Showing a head of	5·25

At Copai bridge, the difference between the two floods was even greater than that of Buckasore.

In the face of such evidence, the proximate cause of failure must be attributed to insufficient water-way. There is, however, another element of failure I would refer to, that is, in the coffer blocks sunk under the arches at Copai and Buckasore bridges. The blocks are built 16 feet from clay strata to dry-weather bed of nullah. The resistance of such a mass of solid masonry opposed to a depth of 40 feet of flood-water, running at a velocity due to a head of 5 feet 3 inches at

the Buckasore bridge, and that of 4 feet $5\frac{1}{2}$ inches at the Copai bridge, where there was a similar obstruction, must not alone have acted injuriously, but may have been directly the cause of the two bridges failing.

Without such an obstruction as that offered by coffer blocks, the effect might have been reduced to a scour, even as deep as the clay bottom, without further affecting the stability of either of the bridges.

I am strengthened in the foregoing remarks concerning the two bridges, Copai and Buckasore, by my experience of the results at other bridges where no similar obstruction exists in the bed of the streams, and where, in many instances, the bridges were subjected to an equally severe test, without leaving any indication of failure after the floods had subsided.

From J. F. Cockburn, Esq., District Engineer, to Chief Engineer, E. I. R.—Dated 18*th July*, 1866.

Having now had time to examine the bridges between the Junction and Bhulpoor with some degree of care, I beg to report briefly the effect of the flood upon them :—

Khurry Nullah Bridge, nine 24-feet arches at $78\frac{1}{2}$ miles, platforms and drop-walls both sides, and convex wing-walls supporting slopes at abutments, with slopes of ballast and turfed earth in front of them, and continued through against the abutments.—In putting in the protective works here, the water-way was nearly doubled, and the channel of the river above and below the bridge was widened and straightened.

I also put cut-waters to the up-stream ends of the piers: the flood here rose to springing, or 3 feet higher than I had known it before, with a strong current, but has not done the slightest damage to the bridge, protective works, or slopes.

Two sets, each of ten 15*-feet arches, at* 85 *and* 86 *miles, splayed wing-walls; the latter set protected with platforms and drop-walls.*—There was a great deal of water here, but very little stream ; no damage has occurred.

Fifteen 12*-feet arches at $87\frac{1}{2}$ miles, concave wing-walls, platforms, and drop-walls.*—This bridge carries the surplus flood-water of the Koonoor.

There was a strong rush through it, but no damage has been done

beyond the cutting out of a piece of the bank behind each of the up-stream wings, which holes have now been re-filled with large ballast.

Koonoor Nullah Bridge, seven 20-feet arches at 88 miles, platforms and drop-walls on up-stream side, with convex wing-walls supporting slopes also on the up-side; the southern one flush with the abutment, and northern one flush with the first pier.—The flood here was up to within 3 feet of the soffit of the arches with a very strong stream. The earthen slopes in front of the wing-walls, &c., carried through the abutments, have been almost entirely washed away, but the walls have stood well: the platform is about 7 feet below the head of the channel, and in former years the hollow had silted up flush with the bed. This has scoured out down to within 2 or 3 feet of the platform, but not lower. The slopes above the tops of the wing-walls have been a good deal cut away, and a hole has scoured down behind the northern wing-wall, but not to any serious depth. This and the slopes are now being filled up with ballast, and the best plan will be to pitch them with pucka brick-work up to the level of the soffit of the arches.

Ten 12-feet arches at 89 miles,—no protective works.—Here the Adjai water was running back from east to west into the Koonoor flood with a moderately strong stream, but no scour or damage has taken place.

Five 10-feet arches at 92 miles,—no protective works.—Deep scour both above and below the bridge, down to below the foundation, but, as far as I have yet been able to ascertain, not underneath it. As soon as I have settled this point with certainty, which I hope to do to-morrow, I shall fill up the scoured holes with large ballast.

Three 10-feet arches at 93 miles (Beddiah Station).—This is the bridge which fell. I am having the water baled out in order to examine the foundation, and will then send full particulars.

Two sets, each of three 10-feet arches, just above Beddiah Station.—At the latter of these, there is deep scour, but, so far as I have yet been able to ascertain, not under the foundation.

Through all these four sets of 10-feet arches there was a very violent rush of water.

Ten 20-feet arches at 94½ miles, platforms, drop-walls, and pitching to slopes on both sides of bridge.—On the up-side, the lower part of the pitching was pucka: the upper 5 feet kucha-pucka: this latter portion has entirely gone, but the lower pucka portion is intact. Platform

and drop-walls sound, and the scour in front of the drop-wall nowhere more than about 2 feet below top of platform (all the drop-walls here and elsewhere are 6 feet deep). The slopes above top of pitching have been a good deal cut away, but not dangerously. Down-stream side no damage.

Ten 20-feet arches at 94¾ miles, protective platforms, drop-walls, and pitched slopes (all pucka) on both sides of bridge.—At this bridge, the rush of water was even more violent than at the last. There were long rolling waves of considerable height opposite the centre arches, and a large curling wave at the south-west corner. The effect of the latter was to scour out a hole 20 feet diameter and 8 feet deep; but except this, there is no scour much below the top of the platform and drop-walls. Both these are quite perfect all along: at the south-west corner, a portion of the slope, and a small bit of the upper outer corner of the pitching, have been carried away: the rest is perfect; at the north-west corner of the bridge, a very large piece of the slope has been washed out, forming a nearly perpendicular face at the end of the abutment wall, and all the upper part of the pitching has gone. The lower part, however, where it joins the platform, has remained unmoved, and a good deal of the upper part has fallen down behind it in large masses, which have formed a support to the foot of the remains of the slope, and a protective cover to the end of the platform. I propose at this bridge, and the last, to fill up the slopes with large stone rubble and ballast, and partially to re-build the pucka pitching. Down-stream side no damage.

The Adjai bridge has suffered no damage.

Three 20-feet arches at 95½ miles, platforms, drop-walls, and pitching to slopes both sides.—Here also the upper part of the pitching was kucha-pucka, but the whole of it has stood uninjured, though there was a very strong rush of water through the bridge.

Three 28-feet girder openings at 96½ miles, splayed wing-walls, platforms, and drop-walls to centre opening and half of each side ditto, with retaining walls to support road-way.—There has been some scour at the corners of the wing-walls and retaining walls, but not serious.

At this, and the last bridge, I have not yet had time to sound the platforms, but will do so as soon as possible. I have, however, every reason to suppose that they have stood as well as the others.

From S. Power, Esq., Chief Engineer, E. I. R. Lower Division, to Chairman, Board of Agency, E. I. R.—Dated 28th August, 1866.

This office letter of 7th July, described the failure of the Buckasore, Copai, and Beddiah Bridges on the 1st July, and the consequent stoppage of the traffic; also the remedial measures which were at once adopted, and by means of which the passenger traffic was re-opened on the 10th July, and the goods traffic a few days later.

In compliance with the wishes of the Government of India, the accompanying drawings and the Reports of Messrs. Cockburn and Latimer are now submitted. They exhibit and describe in detail the structure of these bridges, and the injuries which they have sustained; the remedial measures which have been extensively adopted with success, and those which have been tried in a few cases, and have failed; and also the proposed improvements.

There is also appended a Tabular Statement which shows the areas of the basins drained by the great rivers and their tributaries which are crossed by this Railway: the water-way afforded by the existing bridges, and the velocity with which the water must have passed through them, assuming that they have, during recorded floods, discharged a rain-fall of half an inch per hour; this being half the quantity which was ascertained by Mr. Levinge's careful experiment, to have fallen in the basin of the Gerooah during the great flood of 1861. No other trustworthy record of the rain-fall has been kept by the Railway Officers.

The cause of the failure of the bridges must now be considered.

It might have been a defect in construction or in design, a deficiency of water-way, or insufficient depth of foundation.

It did not arise from any defect of construction, because both workmanship and materials are indisputably excellent; nor from a faulty design, because the general plan is perfect of its kind, and that which has been almost universally adopted with success.

It must, therefore, have arisen from a deficiency of the water-way, or from the insufficient depth of the foundations.

A sufficiency of water-way is generally supposed to include the following conditions:—

1st.—That the floods shall not rise above the embankments.

2nd.—That the extent of inundated land shall not be injuriously increased.

3rd.—That the velocity of the water passing through the bridges shall not be so great as to scour away the clay or other material on which their foundations rest.

If this definition be assumed to be correct, it must at once be admitted that the failure was caused by the non-fulfilment of the third condition, because the clay was certainly scoured from beneath the piers, which settled or fell when the ground on which they rested was carried away; and, moreover, it is shown by the annexed Tabular Statement, that the velocity of the water from a rain-fall of half-an-inch, must necessarily have been such as to produce this effect, being nearly five times that which most recent and careful observations show to be the safe velocity, viz., $2\frac{1}{2}$ feet; and finally, it is shown by the levels since taken by Mr. Latimer, that the head of water exceeded 5 feet, which must have produced a velocity of 16 feet per second.

It is scarcely necessary to point out that this investigation entirely confirms the truth of Mr. Turnbull's opinion, that the water-way was insufficient, and that every addition to it must have increased the chances of safety.

But unhappily the enquiry also proves that the deficiency is so great that no moderate addition to the bridges will insure, or, perhaps, on the whole, appreciably increase their safety; and that, although for several reasons, a large addition to the water-way will, in many particular places, be advisable, the chief remedy for the dangerous condition of the bridges must be sought,—not in this extension alone,—but in rendering them, as nearly as practicable, safe from the effects of the most violent scour.

4th—The insufficient depth of the foundations is another cause which has to be considered.

The surface of the clay, which underlies the sand or silt in the beds of these rivers, appears to have been assumed to be the limit of the scour, because the latter (viz., the sand or silt) was probably deposited by one flood, and liable to be removed by another; while the surface of the clay had not been disturbed, and therefore, marked with certainty the limit below which the scour of the rivers had not formerly extended. But any departure from the normal condition of the drain-

age must alter this limit, and when the Railway bank was constructed, and all the rain-fall was forced to pass through the bridges, instead of flowing over the ground, the surface of the clay ceased to be the limit of the scour, or the safe depth of foundations.

It would, of course, be possible to calculate approximately the additional depth to which the foundations should be sunk, *i. e.*, that to which the river channels must be deepened, in order that they may be enabled to carry, with a given velocity, the additional water forced through them by dams across the valleys; but, as sinking blocks into the clay was almost impracticable with the implements formerly in use, it is useless to enter further into this matter. The best remedies for the existing evils form a far more important subject of consideration, and they must now be discussed.

In consequence of the excessive quantity of water which has to be discharged through the bridges on this Railway, their position has become somewhat similar to that of canal locks, and the means which have always been found adequate for the security of the latter will certainly be found efficacious in protecting the former: these means are a flooring, which cannot be injured by any possible velocity with which the water can move over it, and the prevention of the passage of water under the flooring, or behind the walls of the lock-chamber or sluices, by means of sheet-piling, or their more permanent, but less effective, substitute, drop-walls, sunk to a sufficient depth in the clay.

In bridges having inverts resting on the clay, this method of protection (viz., a solid flooring and drop-wall) has been easily applied, and has been perfectly successful, except in the case of a small bridge at the 109th mile, where the drop-walls were sunk only 4 feet. But although thus far successful, it exhibits defects which require attention; they are,—the insufficient width of the aprons, the insufficient depth of the drop-walls, and the want of adequate protection behind the wing-walls and abutments. In reference to the first, it was formerly observed that the eddies by which the foundations of the bridges are generally damaged, have been usually produced close to the upper-faces of the bridges. Major Hovenden and I had an opportunity of seeing that the sod covering the surface of the ground had not been disturbed at a distance of 10 feet from the face of the Beddiah bridge, which was, nevertheless,

so completely undermined, that it dropped into a hole scoured under its bottom. On account of the narrow limit within which the scour thus appeared to be confined, the aprons have hitherto been made only 15 feet wide. No mischief has as yet been caused by this limit—no invert bridge, protected in this manner having been damaged; it was, however, I now think injudicious economy on my part, and the aprons should extend to the foot of the slope, and the drop-walls should be sunk to a greater depth (10 feet) where practicable. Moreover, the wing-walls have not in all cases been underpinned to the same depth as the drop-walls; this should now be done in every case, and the bank behind the wing-walls, and for some distance beyond them, should be covered by a solid pavement. These additional precautions will add much to the security of bridges having inverts or floors.

The block bridges and others without floors present far greater difficulty: the Copai and Buckasore belong to this class. In Plate IX., is shown the method of protection tried at Buckasore and other bridges of this class: it fails altogether to prevent the passage of water beneath the platform. Before a trial of this plan was decided upon, an estimate was made of the cost of enclosing the bridge by sheet piling, as shown in Plate VIII.; but this latter design was necessarily abandoned, as the cost was prohibitory in the then existing condition of the Railway; and, indeed, it would rarely be expedient, as a new and better bridge would be far less expensive.

The conclusions to be drawn from the foregoing considerations appear to be these:—

1st.—All the bridges on the Railway should be secured as quickly as possible without waiting for any evidence of scour.

2nd.—The aprons and drop-walls shown in drawings, with adequate protection to the wings, will add much to the security of bridges having inverts and floors which are accessible.

3rd.—An attempt must be made to remove the water from the foundations of all the bridges without flooring, and to protect them also by flooring, aprons and drop-walls sunk at least 6 feet into the clay. When this is found impracticable, as appeared to be the case at Buckasore, the sheet-piling shown in Plate VIII., must be adopted as the last and unfailing resource.

4th.—No decision respecting the exact treatment of the Copai and Buckasore bridges can be arrived at until the dry season, when all available pumping power must be employed to remove the water from their foundations, repair them if practicable, and secure them with flooring, aprons, and drop-walls sunk into the clay. If this be impracticable, or the state of the piers should not warrant the retention of these bridges, new bridges must be erected.

5th.—The water-way must be increased in many places as an adjunct to the protective measures.

EAST INDIAN RAILWAY.

Comparative Statement of Water-way on the several Districts of the Main Line in the Bengal Division.

Names of Rivers	Area of basin to be drained	Water-way given in the Railway Embankment: Lineal feet	Water-way given in the Railway Embankment: Square feet below recorded flood-level	Area of water-way below recorded flood-level, per square mile	Estimated amount of rain-fall to be carried off through the Railway, vertical inches per hour	Quantity of water to be discharged per square foot of water-way per second to carry off this estimated rain-fall	Mean velocity at which water must have passed through the Railway openings if this estimated rain-fall has been carried off.	Estimated addition to existing water-way required to reduce this velocity through bridges below 2·5 feet per second, existing water-way being 1.	Remarks
	Sq. miles.			Square ft		Cubic ft	Lineal ft per scd		
1. Kurumnassa	3,400	4,000	39,000	11	·25	162	15	6	The rain-fall over these districts is comparatively light.
2. Soane river	23,000	14,200	172,500	8	·125	81	10	4	
3. Poon-poon and Hullohur valleys	9,000	11,086	123,648	14	·25	162	11	4	
4. Keeul river	1,100	1,542	11,002	10	·25	162	16	6	
5. Hill streams west of Jamalpoor	240	1,670	7,385	80	·5	323	10	4	
6 Ditto from Jamalpoor to Sahebgung	2,650	6,796	59,486	23	·5	323	14	5	The rain-fall over this country is much heavier than in the districts west of Monghyr.
7. Ditto from Sahebgung to Teenpahar	52	1,641	7,952	155	·5	323	2	1	
8. Ditto from Teenpahar to Bahawa	66	1,176	2,476	144	·5	323	2	1	
9. Gomanee river	520	1,639	10,165	20	·5	323	16	6	
10. Hill streams between Gomanee river and Mullarpoor	1,200	5,824	53,301	44	·5	323	7	3	
11. Adjai and More valleys	3,640	7,752	120,300	30	·5	323	10	4	
12. Khanoo to Howrah	*	14,000	65,000	..	...	...	...	...	* The drainage area is uncertain, owing to the river Damoodur being embanked and liable to overflow.

NOTE 1.—Much doubt exists as to the effect of running water on different substances.

It was formerly supposed that a velocity of 6 inches per second moved ordinary clay. Mr Blackwell's experiments in 1857 appeared to show that a velocity of $2\frac{1}{2}$ per second would move a brick-bat weighing 9 oz

Major Crofton, however, considers $2\frac{1}{2}$ feet to be a safe velocity on clay, and it has been adopted in this Statement lest the Table should appear exaggerated.

NOTE 2.—No attempt has been made to divide the drainage of the great basins, and to show the discharge of each tributary separately, because the inosculation of many of the rivers renders a correct division impossible. The Kandour, one of the southern tributaries of the Adjai, may be taken as an example of this difficulty; the Adjai burst its south bank, filled the valley of the Kandour, topped the Railway bank, and swept away the Beddiah bridge. Colonel Short, whose authority cannot be questioned, informs me that this irruption of the Adjai took place on the 1st and 2nd July.

CALCUTTA,
28th August, 1866.

S. POWER,
Chief Engineer.

No. CXXXV.

GRAND RIVER VIADUCT—MAURITIUS.

Abridged from the Minutes of Proceedings of the Institution of Civil Engineers for 1865-66. By William Ridley.

The viaduct to be described in this Paper was erected over the Grand River Ravine, on the Midland line of the Mauritius Railways. It was designed by Mr. Hawkshaw, the Consulting Engineer to the Government of Mauritius, and was constructed by Messrs. Thomas Brassey and Co., the Contractors for the above-named railways, under the superintendence of Mr. Longridge (M. Inst. C.E.), their Agent in the Mauritius.

The total span of the viaduct, from abutment to abutment, is 620 feet, and this distance is divided into five openings of 116 feet each in the clear. The height from the surface of the water to the level of the rails is 129 feet 9 inches. Plate X., Fig 1.

Each pier is composed of two cast-iron cylinders, each 10 feet in diameter, resting on masonry foundations, and filled with concrete. The method of constructing the piers is shown in Plate X. Cylindric rings, 9 feet high, were divided into five segments each, and were bolted together by internal flanges. The horizontal joints were "rusted up" with iron cement, well beaten in.

The works were commenced May 4th, 1863. The abutment on the Port Louis side was built upon hard tufa, and contains 370 cubic yards of masonry. No. 1 pier was commenced in July 1863, upon a rock projecting on the side of the ravine. The part upon which the pier stands was truly levelled, and the rock well faced up with masonry set in cement. The total amount of masonry in this pier is 92 cubic yards. During the excavation for the foundation of No. 2 pier, considerable trouble was caus-

ed, owing to the pier being situated close to the edge of the river, and from the nature of the ground, which consisted of large boulders and fine river gravel, the water freely percolating on all sides of the excavation. This foundation was commenced August 8th, 1863, and was completed September 31st in the same year. At first it was thought, that the water might be kept out by a series of dams [*Plate* X., *Fig.* 4], and with that view a mass of stiff red clay was thrown into the river, and piles were driven as far down as possible, at intervals of about 18 inches; and in front of these were placed a waling piece and sheet piles. When the work was so far completed, a similar row of piles was introduced at a distance of 3 feet 6 inches from the former, the space between the two rows being well puddled, and made as water-tight as possible. The excavation was then continued, and a third and a fourth row of piles were driven, and the excavation again carried down.

It was intended, had it proved practicable, to proceed in this manner, placing each dam successively lower than the one in front of it, until the required depth was arrived at. This method proved insufficient, for although the water was, to a great extent, prevented passing through the dams, yet it found its way through the bottom in such quantities, that the employment of steam power became necessary. A centrifugal pump, on Woodford's plan, was now introduced, and was worked by an engine of 14 horse-power. When the excavation had reached a depth of 5 feet below the level of the river, the water increased so much, that another similar pump was placed by the side of the first, and in order to render the working of the pumps more effectual, the four straight discharge-pipes, of 4 inches in diameter, were widened out at the discharge ends to a diameter of $8\frac{1}{2}$ inches, giving together an area of 224 square inches. The effect of this alteration was, that nearly twice the amount of water was discharged. The pulley sheaves fixed on the spindles of the pumps were 18 inches in diameter, and were rotated by belts passing over the fly-wheels of the engine, which were each 5 feet in diameter. The number of revolutions made by the pumps was 300 per minute, and the amount of water discharged by the two pumps (after the pipes had been widened out) was nearly 3,000 gallons per minute, or 8 cubic feet per second. [*Plate* X., *Figs.* 5 and 6.]

It was next resolved that the foundations should be laid in blocks of concrete, and that sufficient excavation for one block only should be taken out at a time. The bed of the river adjacent to the pier was of the same material as that which had been excavated—that is to say, it was composed

of boulders and gravel; and the river just opposite to the pier was 20 feet deep. Hence, and from the general appearance of the neighbouring ground, it was conjectured that it would be useless to attempt to seek for a foundation upon the solid rock. It was therefore decided, that the excavation should be continued to a depth of 10 feet below the lowest water level, and that the bed of the river should be raised with large stones, so as to be from 3 feet to 4 feet under the same level. In justification of this decision it should be mentioned, that although the depth of the water immediately opposite the pier was, as before stated, 20 feet, yet that depth was quite exceptional, and existed only for a short distance above and below the pier. It was, in fact, a pool of comparatively stagnant water, and might therefore, safely be filled up, without fear of increasing the scour in other parts of the river bed.

The excavation for the first block of concrete was carried on and piled as shown in [*Plate* X., *Fig.* 5]. A row of close piling, 8 inches square, was driven as far as possible. This was a tedious and difficult operation, from the quantity and size of the boulders, and from the strong springs of water which came up through the bottom. Owing, however, to the limited area exposed at one time, and the considerable amount of pumping power, the piling was at length got down to the full depth, and was shored horizontally in both directions. A waling piece, 12 inches square, was next bolted to the top, and the whole of the inside of the dam was planked horizontally, and caulked. Drains were cut at the bottom of the excavation to allow the water to run off to the well sunk for the pumps. Tarpaulins were laid in the bottom, and for 4 feet up the sides of the excavation, for the purpose of preventing the numerous springs of water from washing out the cement, and also to turn the water into the drains leading to the pump-well. This plan was found to answer, little cement being washed out. When this block was filled with concrete, a second was excavated and treated in the same manner, the piles between it and the first block being drawn as the concrete was put in.

The whole of this foundation was thus successively laid, five blocks of concrete, each 7 feet deep, and measuring respectively 10 feet by 18, 10 feet by 10, 13 feet by 18, 10 feet by 4 feet, and 10 feet by 4 feet, being employed. The concrete was composed of Portland cement 5 parts, sand 6 parts, and broken stone 20 parts. It was laid in layers of 12 inches thick, well punned down, and after every two or three layers it was grouted

with cement. *Plate* X., *Fig.* 6, shows a section of the excavation, and the position of the pumps, which were on the site of No. 5 block of concrete. This block, which was the last, was not laid until some days after the others, which were kept dry until well set by working the pumps; when the latter were removed the space occupied by them was filled up with concrete. On this bed of concrete, a block of ashlar, 30 feet 6 inches long, 17 feet 6 inches broad, and 3 feet deep was set in cement, the upper surface being carefully chisel-dressed and levelled to receive the sole-plates of the piers.

The foundation for No. 3 pier was commenced August 5th, and was completed September 30th, 1863; the work being carried on at intervals only. It was of the same description as that of No. 2 pier. A double-acting pump, worked by hand, was sufficient to keep the excavation dry. A bed of concrete, 33 feet by 18 feet by 5 feet thick, was deposited in layers, and treated in a similar way to that already described, and on this a slab of ashlar, 1 foot deep, of the same length and breadth as that of No. 2 pier, was set. The concrete in this case was composed of 5 parts of lime, 5 parts of sand, and 20 parts of broken stone.

No. 4 pier was founded upon rock and hard tufa, some little distance up the side of the ravine; the surface being levelled with cement concrete, on which, as in the other piers, was laid a course of ashlar, 14 inches deep. This foundation was commenced October 14th, and was completed on the 20th of the same month.

No. 2 abutment contains 650 cubic yards of masonry. It was built upon hard tufa, and was commenced August 4th, 1863.

The cast-iron cylinders rested on sole-plates, 2¼ inches thick, which were bolted together with turned bolts. These were levelled and well beaten in with iron cement, between the top of the masonry and the underside of the plates, as were also the joints. The lower ring of each cylinder was 2¼ inches thick, increased at the bottom edge to 3 inches. The other rings were only 1½ inches thick. After the segments were cast, they were bolted together in rings, and mounted on a frame, consisting of two large wheels and a spindle 7 inches in diameter. At first the ring remained fixed, and the spindle, with an arm 5 feet long, to which was attached the cutting tool, was made to revolve; but this not proving satisfactory, the ring was made to revolve on a new cast-iron hollow shaft 12 inches in diameter, whilst the cutting tool remained fixed at the bottom of the frame.

The segments for the first rings of each pier were lifted into their places on the works by means of "sheer-legs" and tackle, and in two cases the second rings also; but afterwards a plan designed by Mr. Longridge, was used for lifting the remaining rings [*Plate* X., *Fig.* 7]. A mast, 23 feet 8 inches long, with a cross-tree and struts, was mounted on a frame, inside the cylinder, the frame resting on the flanges of the segments, and being supported by small side frames. There was another frame, acting as a guide to the mast, which passed through it in a collar. At the foot of the mast was a pivot, which worked in a foot-piece resting on the top of the frame, thus enabling it to revolve easily when required. A chain, passing over and lashed to the cross-tree, was secured at one end to an eye-bolt fixed through one of the bolt holes in the top flange of the ring already completed, whilst to the other was lashed a three-sheave block. The segments were then lifted in the following manner. An eye-bolt and shackle, to which was fixed a two-sheave block, was fastened through a bolt hole in the top of the segment, a 4½-inch "fall" was passed round these blocks, and led away to a gin crab fixed in the bottom of the ravine. When it was required to raise the mast, a light frame holding two sheaves was laid on the top of the ring just completed, and bolted to its upper flanges; a rope fastened to it passed down under a sheave fixed for the purpose in the foot of the mast, returning up, and passing over the sheaves of the frame to the crab, and the mast was thus raised, taking with it its supporting frames, which had been previously loosened and lashed to the hooks at the sides of the mast; guy ropes being secured to the top, and gently eased away whilst the mast was being lifted. The time occupied in raising these masts was about four hours and a half. In this manner all the piers were erected without a single accident. The mast was 10 inches square, but tapered and rounded at the foot to allow it to turn freely. The cross-tree consisted of two planks, each 10 inches by 4 inches, and between the planks, and at their ends, were fixed two sheaves. All the timber work was of teak, and the mast, complete, weighed about 2 tons.

Eleven pairs of rings were thus lifted on No. 1 pier, thirteen on No. 2, thirteen on No. 3, and ten on No. 4. The heights to the top of the last ring on each pier were respectively, 99, 117, 117, and 90 feet, and the weight of each segment lifted was 32 cwts. One set of men in one day lifted the mast and one complete ring. After the cornice pieces of the piers were fixed, the masts were removed.

When the piers were in progress, the most convenient method for filling them with concrete was considered. Piers Nos. 1 and 4 were filled from the adjoining abutments; but at piers Nos. 2 and 3, the concrete was lifted by means of an endless ladder. This ladder, with its framework, was worked by a small engine of 5 horse-power. A frame was fitted between the columns of the pier, which were 3 feet 6 inches apart, and upon it was mounted a drum, 4 feet in diameter, havingc ams round its periphery, which caught against the links of the ladder and turned it. A cog-wheel fixed to the spindle of the drum was turned by a pinion on the shaft of the belt wheel. On the top of the cylinders rested another frame holding a similar drum, but without cams. The ladder passed over these drums. The links were each 2 feet long, and were connected together by bolts $\frac{3}{4}$ths of an inch in diameter. At every alternate joint was fixed, by angle pieces and diagonal stays, a light deal shelf, sufficiently large to hold a basket containing nearly a cubic foot of concrete. The ladder was of iron 1 inch by $\frac{3}{8}$ths of an inch. The concrete in the cylinders consisted of 2 parts of lime, 3 parts of sand, and 10 of broken stone. When mixed it was put into baskets, which were carried to the tops of the piers by the ladder, where it was lifted off and thrown into the cylinders, the baskets being returned on the underside of the ladder shelves.

Piers Nos. 1 and 4 were filled by a different plan. A frame, 3 feet 9 inches high, was fixed on the top of the columns at the far side of the pier; a similar frame, but 7 feet 6 inches high, was placed on the abutment, and over these two frames a single contractor's rail, weighing 23 lbs. per lineal yard, was suspended. A box, with a false bottom, was conveyed under the rail, by a sheave rolling over it. When filled with concrete, the box was set loose, and travelled along the rail till it arrived over the centre of the pier. A small line was fixed at the back by which it could be prevented moving too quickly and striking the frame on the pier. The weight of the box, when filled, was $8\frac{1}{2}$ cwts., and it contained 7 cubic feet. A chain was fixed from the frame on the pier to the foot of the next pier, to guard against any undue strain which might be thrown on it from the concrete box. When the box arrived over the pier, the catch which held up the bottom was withdrawn, allowing it to fall back upon its hinges, and discharge the contents into the cylinders. The box, when emptied, was drawn back by the rope attached to it. The average amount of work done daily in this way was 50 cubic yards, whilst by the endless ladder, at the other

piers, about 40 cubic yards were deposited, with one hundred men working at each.

A cylinder, 6 feet long, and 9 inches in diameter, was bedded into the concrete at the top of each column, to serve as a holding-down bolt for the bed-plates, which were lifted in pieces, weighing each 2 tons, by a fall fastened to a slight scaffold made of timber 9 inches square; the ends of the upright posts fitting into the holding-down cylinders. The bed-plates for the tops of the piers weighed 16 tons each, complete, and were cast in eight pieces, bolted together with turned bolts. The upper surfaces upon which rested the expansion rollers and bearing pieces were planed. The bed-plates extended across both cylinders, and were 23 feet 6 inches long by 10 feet wide, and 18 inches deep, the thickness of the metal being $2\frac{1}{2}$ inches. These, when *in situ*, were wedged up to their proper levels, and beaten in underneath with cement concrete. The concrete was carried up to a height of 3 inches above the tops of the cylinders, and bore the whole weight resting on the piers, the cylinders merely serving the purpose of a casing, and preventing the concrete from crushing laterally [*Plate* XI., *Fig.* 11].

It was originally intended to erect the piers in the following manner:— A length of girders braced together and with roadway plates complete, of about 300 lineal feet, was to have been built at the proper level on the bank of the ravine, and to have been trussed by a standard and by suspension chains (*Plate* XI, *Fig.* 8), and a jib crane fixed at the end. The girders were then to have been pushed forward, until the crane commanded the site of the first pier, when the segments and bed-plates of the piers were to have been run along the girders on bogies, and have been lowered into their places. The concrete was in the same way to have been filled in from the top, and the top bed-plates fixed. Whilst this was in progress, additional lengths of girders were to have been added on the land end, and as soon as the first pier was finished, the girders were to have been advanced another span, and so on till the whole of the piers were completed. But the girders were not ready for shipment till many months after the whole of the cast-iron segments for the piers had arrived in the Mauritius, and therefore the erection of the piers was proceeded with by a separate process, as has already been described. The girders were sent from England in sections of about 12 feet long, which on arrival were transported to the Mahébourg side of the ravine, and were riveted together in lengths of from 36 to 48 feet. A gullet, extending backwards to a distance of about 280 feet was excavated to the

level of the abutment; and it rose at a slope of about 1 in 5 to the formation level [*Fig.* 8]. In this gullet the first lengths of the girders were to be built, and the succeeding sections of 36 or 48 feet were to be brought down the incline into the gullet and added as the first were pushed forwards.

The arrangement for launching the girders was, however, considerably modified in England. This modification may be described as follows :—A keel plate, $3\frac{1}{2}$ inches wide by 1 inch deep was fixed under the centre of each girder, to which it was fastened by countersunk bolts, and this plate passed over shallow grooves turned in the tops of rollers, for the purpose of receiving them, as well as of acting as guides to keep the girders perfectly straight whilst travelling. The rollers were 7 inches in diameter, and rested upon bed-plates [*Fig.* 9]. On one end of them a ratchet was cast, and a space was left outside, to receive a cast-iron lever head; and outside this again an iron ring was bolted, to prevent the lever head from sliding off: a similar ring was fastened on the other end of the roller, to prevent its travelling laterally along its bed-plate. The bed-plates of the rollers were laid upon and bolted to timbers 8 inches deep by 16 inches broad, the latter being laid on a course of ashlar masonry. The rollers were placed 36 feet apart, and were turned by levers each 9 feet long, and between them three lines of rails were laid, upon which a sufficient length of girder for launching was built. The girders were next lowered down upon the rollers, and the levers fixed in their places; a steel pall was bolted to each lever head, which worked in the ratchet cast on the roller, and thus caused it to rotate. The levers were connected together by a rope, securely lashed to their top ends; the lever on the abutment being made in the form of a bell crank, and the rope passed over the ends of its two arms to the winches below, placed in front of the abutment; the whole of the levers, thus connected, worked together simultaneously. The other end of the rope was attached to a crab, which pulled the levers back again when the stroke was completed. As the girders were launched, sections, each 36 feet long, were joined on at the back end.

The launching was commenced on Thursday afternoon, April 18th, 1865, and the girders were propelled forwards a distance of 2 feet 6 inches, at the rate of 1 inch per minute. No further attempt at launching was made until the following Saturday, when the girders were only advanced 1 foot 8 inches, during the whole day. The cause of this failure was due to the keel-plates rolling out; for a portion, 4 feet in length, was elongated 2 inches, and thus jammed against the roller. At first only three sets of rol-

lers were laid, [*Fig.* 8,] but four more sets were subsequently added. The length of girder moved, when the launching was first commenced, was 252 feet, and it weighed about 190 tons, including the tension chains and standards, which trussed the girders during the construction of the piers. One of the great difficulties was the irregularity of the underside of the lower flange of the girder, arising from the cover plates of the joints and the strengthening plates, and also in some measure from the camber of the girder itself.

When the keel plate rolled out, serious doubts were entertained as to the practicability of launching by rollers, on account of the great friction from their turning in their bed-plates, and from the probable continuous elongation of the keel-plates. To overcome this last objection, it was resolved to place loose keels under the fixed ones, to keep them off the rollers. These were made in short lengths of about 4 feet, each 3½ inches wide, and varying in thickness as required by the camber and other irregularities on the under side of the girders.

On Saturday, April 22nd, another and more successful attempt at launching was made. The introduction of the short keel-plates was found to be a great improvement, ample space being thus afforded for their elongation, in case of rolling out. Some were tapered off at one or both ends, to allow of easy entrance and progress. The launching commenced at 11·30 A.M., and was successfully carried on till 4·15 P.M., the girders being propelled a distance of 39 feet in the four hours and forty-five minutes. In addition to the two double-purchase winches working the levers in front of the abutment, a 9-inch rope, reeved round a pair of three-sheave blocks, was fixed to the back end of the girder, and was moved by the means before noticed, the strain being reduced by a smaller set of blocks with a 6-inch fall. The number of men employed was 18 at the winches working the levers, 18 at the winches hauling the levers back, 28 at the rollers, following up with the small keel-plates, 14 at the levers, attending to the palls, &c., and 1 engine driver; in all 79.

On the Saturday following, the girders were launched a further distance of 40 feet 6 inches, which was accomplished in five hours; one being spent in re-adjusting the keel-plates, levers, &c. At each stroke of the levers, the girders were propelled a distance varying from 3 inches to 4 inches.

On Monday, after another launch of 12 feet was effected, the keel-plates over the first rollers completely failed, by buckling over. The strain was very great, for a length of 95 feet of girder was overhanging, whilst the

rollers were supporting the weight of nearly twice this length. The iron of the keel-plates was crushed by the weight, the rollers in front surged at each stroke, and the lever heads broke across the bottom.

The girders had now to be lifted; the damaged keel-plates to be removed and replaced, as also the broken lever heads. Another attempt was then made, but with little success, the lever heads again breaking, and the keels crushing. These were repaired, and on the following day the girders were propelled 10 feet, after the application of an additional power of two 8-ton jacks at the back end of the girder, when failure again ensued from the same causes. In order to relieve, to some extent, the weight on the first rollers, which were the only ones that failed, 30 permanent way rails, weighing 5 cwts. each, were placed at right angles, lever-wise under each girder, as near the rollers as possible. Each of these rails acted with a force of 15 cwts., and, together, were to a great degree effective. But still, the launching was unsatisfactory, and was followed by successive failures and breakages, with the additional failure of the front rollers, through their ratchets being stripped of nearly all the cogs or teeth. The girders were, however, finally but with considerable difficulty, landed on the first pier. The deflection of the end of the girder just before it touched the pier was 7 inches.

It was now unmistakeably evident, that this mode of launching, simple and effective as it had appeared to be, and good as it was theoretically, was practically a failure, and that the original plan must be resorted to. The following method was now introduced for the portion of the girder resting on the abutment and in the gullet. Throughout the gullet, and up to within 5 feet of the face of the abutment, a line of flat-bottomed permanent way, (the underside of the rails being level with the masonry,) was laid under the centre of each girder, and on longitudinal timbers, resting on cross-sleepers. At every 12 feet a baulk of timber, 9 inches square, forming a skid, was placed transversely across the rails; upon these baulks the girders were wedged up. A thin plate of iron was fixed on the underside of each skid, over that part which would bear upon the rails; two bolts passed through it, the heads being let in flush with the surface of the top, whilst the nuts, projecting underneath, came close up to the inside edges of the rails, and acted as guides to keep the girder in line when travelling.

When the girders were ready to be moved, the rails were well greased, and men were placed at the ends of each skid with sledge-hammers to

keep striking it to prevent sticking, as well as to assist in starting. The skids, after arriving successively, gently pressed over the ends of the rails, dropped, and were removed.

The following was the manner of placing the rollers on the piers. [*Figs.* 10 and 11.] On the top of the bed-plates, the bearing plates for the permanent expension rollers were bolted. These plates were $2\frac{1}{4}$ inches thick, and were tapered off at the ends, to allow the rollers to enter and pass freely in and out. The latter were linked together, and after travelling over, the plates were taken out, returned, linked on to the rollers just entered, and were gradually drawn in under the girders. Short pieces of keel-plate, in 4 feet lengths, were followed up on the rollers, as the girders advanced, by men stationed on a scaffold.

On May 15th, everything was again ready to launch; a $\frac{7}{8}$ths of an inch chain, doubled, was secured to the back end of the girders, and passing over a sheave on the edge of the abutment, was fastened to the blocks [*Fig.* 12]. The rope was reeved round a pair of large blocks, that at N being fastened to the foot of the pier, as shown, and led away again to the smaller blocks, over which was reeved a $6\frac{1}{2}$-inch fall, leading to the rope roll on the top of the bank through a snatch-block at F. The chain broke after the girders had been moved a few inches. This however, was removed and replaced by a chain cable $1\frac{3}{4}$ inches thick, and the day following the girder was launched a further distance of 31 feet 6 inches, when the large block at L broke. This was soon replaced, and the next day, between 1-15 and 4-30 P.M., the girders were advanced a distance of 62 feet 6 inches. The rate of travelling was 12 feet every fifteen minutes, when it became necessary to overhaul the small set of blocks, which occupied twenty minutes each time.

On Thursday, May 18th, the girders were on No. 3 pier. On the 24th, No. 2 pier was reached, the greatest distance travelled, as yet, in one day, being 108 feet in four hours. On Saturday, June 10th, the girders were landed on the Port Louis abutment, in six hours and twenty minutes, the entire length of the girders, 630 feet, moving quite easily. Another rope was secured to the other end of the girders on its reaching No. 1 pier, and passed round a double purchase winch placed on the Port Louis abutment. Thus an additional motive power was added and the whole of the launching was completed most satisfactorily.

The roadway girders, plates and permanent way, were soon and easily laid; and fourteen days after the launching was finished, trains were run-

ning over the viaduct. The entire work was completed on Saturday, the 29th of July.

The total weight of the superstructure is 560 tons, of which 142 tons is the weight of the roadway; and the total weight of iron work in the piers, including bed-plates, expansion-rollers, &c., is 933 tons.

The total cost of this viaduct was upwards of £30,000, or about £50 per foot forward. The cast-iron columns which were sent from England, cost, in erecting, about 28*s.* per ton. The expense of launching the girders was considerable, owing to the disasters that were, in the first instance, met with; it amounted to nearly £5 10*s.* per ton, including the riveting up of the sections of the girders, plant, cutting out the gullet and labor. Had the plan that was subsequently adopted been proceeded with in the first instance, the launching would probably not have cost more than £3 10*s.* ton, as was shown by the fact that one complete span was launched, with the whole weight moved, in about seven hours, by the labor of not more than 100 men. The cast-iron columns delivered cost £8 per ton, and the cost of transport to the place was about £1 per ton, which added to 28*s.* per ton for erection, made nearly £10 10*s.* per ton in place. The wrought-iron work delivered in the Mauritius cost £16 per ton, £1 per ton transport, and £23 per ton in place. The land carriage was about 4 miles, over some very steep hills.

In all the large bridges on the Madras Railway, the mode of getting the girders in place was similar to that above described. The spans of the girders were however less, being 70 feet from centre to centre, while those of the Grand River Viaduct were 116 feet. The Madras girders were continuous, principally with the object of getting them into place in this simple and efficient way; they were connected in lengths of 140 feet, or enough to cover two spans, each length consisting of three pieces, one central piece 36 feet long, and two end pieces, each 52 feet long. By means of strong tackle, no difficulty was found in bringing the girders over the piers by rollers, from one end of the bridge to the other, successively continuing them, one after the other, till the whole series was completed. In the first instance, that of the Palar bridge, planks and wooden rollers were used, and some difficulties were met with in consequence. But by employing inverted rails fixed to the bottom of the girders, and cast-iron rollers on the piers, the superstructures of the bridges over the Cavery, Thoota, and Chey-Air, were erected with perfect success.

No. CXXXVI.

RAJPOOTANA ROAD SPECIFICATIONS.

General specification for Roads in Rajpootana and the Native States in Central India. Drawn up by MAJOR POLLARD, R.E., *Superintending Engineer.*

Preliminary Remarks.—In preparing a scheme of communications, and opening out a comparatively new and vast tract of country with varied, and often unprofessional and untrained agency, the necessity of a standard of reference to ensure uniformity is too obvious to require argument. Such a standard will save many references, and perchance some misunderstandings, as to the style of work projected; and the general details will be of great assistance to the Political Agents, in their dealings with the Native Chiefs on the subject of roads, enabling them to give a distinct and prompt reply to all questions regarding the quantity of land to be surrendered; but the general specifications here given can never supersede the more detailed specification which should accompany an Estimate for the elaborated scheme.

It may probably be urged against the adoption of the standard, as here proposed, that the specification for the minor lines of communication is of too high an order, and that metalling, for instance, is superfluous on a 3rd class road. The reply is, that the specifications are intended to apply to completed roads of their several classes; and it must be admitted that every line of communication, deserving the name of a finished road, should be passable at all seasons and in all weathers for the style of traffic, whether wheeled vehicles, or beasts of burden, for which it was constructed.

Every completed road necessarily consists of three main items:—

1. Earthwork (including embankment, excavation and drainage).
2. Bridging.
3. Metalling.

If any of these are omitted, the road is liable to obstruction, and is an "incomplete" road of that class according to which it was projected.

In cases where it is not desirable to undertake the full expenditure necessary to complete the road according to the specification of its class, it will be sufficient to specify it as a "2nd class road, unmetalled;" or a "3rd class road, unmetalled and unbridged, &c., &c."

Such a sub-division of the classes will convey an accurate idea of the style of road projected; and by ensuring uniformity, will admit a comparison in point of cost with others of a similar character.

General Description.—Roads will be divided into four classes. Classes 1 and 2 will be metalled up to a certain fixed water-way, and will differ merely in width, both being adapted for quick traffic in all weathers.

A 3rd class road will likewise be available for traffic in all weathers; but the metalling of the road-surface will be inferior, and the larger bridges suited for a single line of traffic only.

A 4th class road will be unmetalled and unbridged; in fact merely a fair-weather road on which the ground has been cleared, and the nullahs made passable. It may be regarded as a commencement of a 3rd class road.

Width of Land to be taken up for Roads.—The surrender of land for communication is always distasteful to the rulers and cultivators of a Native State, but doubly so when the ground required is capable of producing valuable crops,—such as opium, sugar-cane, tobacco,—for which special qualities of soil are required. When such land is of necessity absorbed within the road limits, it is advisable to reduce the width to a minimum, without prejudice to the absolute requirements of the highway. This is simply managed by diminishing the side gutter, and giving up its exterior slope altogether. In the specifications, therefore, two breadths are shown, —the narrower of which should be adopted where the land is of more than ordinary value.

Specification of a 1st class Road—[*See Figs.* 1, 2, 3].—For a 1st class road, in ordinary land the width required is 108 feet, divided as follows:—

Roadway, ...	30 feet.
Side slopes, 2 × 4, ...	8 „
Berm or cess, 2 × 15, ...	30 „
Side trenches, 2 × 20, ...	40 „
Total, ..	108 „

This has been calculated from the requirements of a 2-foot embankment, with the slopes of 2 to 1. If the embankment exceeds 2 feet, the extra width for the base of the slopes must be taken from the cess.

In valuable land the width may be reduced to 78 feet as follows:—

Roadway, ...	30 feet.
Side slopes, 2 × 4, ...	8 „
Berm or cess, 2 × 15, ...	30 „
Side trenches, 2 × 5, ...	10 „
Total, ..	78 „

The general specification of a 1st class road is:—

Embanked roadway to be 30 feet wide, with side slopes of 2 base to 1 height.

Gradients not to exceed 1 in 25.

Drains and Culverts, up to 10 feet water-way, to be 30 feet between parapets.

Bridges and Culverts, above 10 feet water-way, to be 20 feet in the clear between parapets.

Metalling in black soil, or where moorum is procurable, to consist of a foundation of 12 inches of moorum, 18 feet wide, well consolidated with a top layer of 6 inches of broken stone or kunkur. Where moorum is not obtainable, and the soil hard and firm, the metalling will be 9 inches of broken stone or kunkur, 12 feet wide.

The Estimate for a 1st class road should include all bridges up to 150 feet water-way. Beyond this, they should be taken up as independent works, and form the subject of separate Estimates.

Specification of a 2nd class Road—[*See Figs.* 4, 5, 6].—For a 2nd class road, in ordinary soil, the width to be taken up is 80 feet, divided as follows:—

Roadway, ...	24 feet.
Side slopes, 2 × 4, ...	8 „
Cess, 2 × 12, ...	24 „
Side gutters, 2 × 12, ...	24 „
Total, ..	80 „

In valuable land the detail will be as follows:—

Roadway, ...	24	feet.
Side slopes, 2 × 4, ...	8	„
Cess, 2 × 12, ...	24	„
Side gutter, 2 × 3, ...	6	„
Total, ..	62	„

The specification of a 2nd class road is:—*Roadway* to be 24 feet wide, and in embankment, to have side slopes of 2 base to 1 height.

Gradients not to exceed 1 in 20.

Drains and Culverts below 10 feet water-way, to be 20 feet wide between parapets.

Bridges and Culverts exceeding 10 feet to 18 feet between parapets.

Metalling in black soil to have a moorum foundation 12 inches thick, 15 feet wide, and a top layer of broken stone or kunkur 9 feet wide and 6 inches thick. In firm soil, where broken stone or kunkur is used, the width will be 9 feet, and thickness 9 inches. The Estimates of a 2nd class road should include all bridges up to 100 feet water-way.

Specification of a 3rd class Road—[*See Figs.* 7, 8, 9].—The land to be taken up for a 3rd class road, under ordinary circumstances, is 72 feet, reducible in valuable land to 54 feet.

The detail of the various parts are:—

Roadway	20	feet.
Side slopes, 2 × 4, ...	8	„
Cess, 2 × 10, ...	20	„
Side gutters, 2 × 12, ...	24	„
Total, ..	72	„

And the decrease, when necessary can be made by reducing the width of the side gutters to 3 feet, as has been shown in the specification of 2nd class road.

The general specification is *roadway* to be 20 feet wide, with side slopes of 2 to 1.

Gradient not to exceed 1 in 20.

Drains and Culverts up to 10 feet water-way to be 18 feet between parapets.

Bridges and Culverts, above 10 feet water-way, to be 14 feet between parapets.

Metalling, where moorum is obtainable, to be of that material exclu-

sively, 14 feet wide and 9 inches thick. Where broken stone or kunkur is used to be 9 feet wide and 9 inches thick.

The Estimate for a 3rd class road should embrace all bridges up to 75 feet water-way.

Specification of a 4th class road.—For a 4th class road, land should be taken up 54 feet wide, and the boundary marked by a small trench. It will not be embanked, but should necessity demand it, it can hereafter be completed as a 3rd class road, of which it is only the commencement.

Its specification is :—

All ground between the boundary trenches to be levelled and cleared; nullahs to be rumped, and made passable for wheeled traffic. All hills or ghâts to be reduced to a gradient not exceeding 1 in 18.

Probable cost per mile.—The cost of these roads will naturally vary according to localities, but it may be set down roughly as follows :—

	RS.
1st class road per mile, ...	14,000
2nd class road ditto, ...	10,000
3rd class road ditto, ...	6,000
4th class road ditto, ...	1,000

A 1st class road being expensive, is only adapted for an artery, connecting the principal Military Depôts; for a main Postal line; or the chief Commercial outlet of the country, where the traffic is such as to warrant the outlay.

A 2nd class road may be adapted to connect the smaller Military Stations with their Reserves, and with each other. It is also suitable for connecting Commercial Marts with the main line, or the chief outlet for their exports, whether this be 1st class road or Railway; whilst

A 3rd class road will be found to suffice for the internal communication of the country between the more populous towns. It will also be found a useful style for short Railway feeders; and where a road is required as an outlet for an isolated district.

A 4th class road must be looked on merely as a preparation for a 3rd class line. Unless greatly favored by Nature, it will be impassible in the rains; but for eight months of the year, it will be found a useful adjunct in many ways, not the least of which will be its habituating the people of the country to the necessity of setting apart a portion of their land for communications.

No. CXXXVII.

PENDULUM OPERATIONS OF THE G. T. SURVEY.

An account of the Pendulum Operations about to be undertaken by the Great Trigonometrical Survey of India; with a sketch of the theory of their application to the determination of the earth's figure. BY CAPTAIN J. P. BASEVI, R.E.

WHILST Lieut.-Colonel Walker, R.E., the Superintendent of the Trigonometrical Survey, was in England last year, General Sabine, the President of the Royal Society, solicited his attention to the importance of making a series of Pendulum observations at the stations of the Great Indian arc, of a similar nature to those made by Captain Kater at the stations of the English arc, and by himself, Captain Henry Foster, and others in various parts of both the Northern and Southern hemispheres. Pendulum observations were made on the French arc by Arago, Biot and Mathieu early in this century; it is also the intention of the Russian Government to have them made at the principal stations of the Russian arc: moreover there is hardly an instance of the measurement of an arc which has not been accompanied by such observations.

General Sabine offered to assist, by placing at the disposal of the Indian Board the pendulums, clocks, and apparatus which he had employed in his own operations; and he added that, should the India Board desire any opinion from the Royal Society on the subject, he would assemble a Committee for the purpose.

Colonel Walker drew up a scheme and estimate of the probable expense, and submitted it with General Sabine's letter for the approval of the Secretary of State for India, who, acting on General Sabine's

suggestion, requested the Royal Society to report on the plan of operations proposed by Colonel Walker.

The President accordingly called for opinions from several distinguished Fellows, viz., Professors Challis, W. H. Miller, Stokes, H. J. S. Smith, Dr. Robinson, Sir G. Everest, and Sir John Herschel; all in their replies were agreed on the scientific value of the operations, and all, with the exception of Sir George Everest,* approved of the proposed plan of carrying them out; several made very valuable suggestions.

The Secretary of State in Council consequently sanctioned the experiments, and on Colonel Walker's recommendations he directed Captain Basevi, R.E., who was then in England on furlough, to proceed to Kew to learn the use of the Pendulum and apparatus, with the view of his conducting the experiments in India.

Before detailing the proposed operations, a sketch of the theory, and of what has hitherto been done in the way of Pendulum experiments, may be interesting. The application of Pendulum experiments to determine the figure of the earth, is based upon a theorem demonstrated by Clairaut, which may be stated thus, that the sum of the ellipticity† of the earth, and the fraction expressing the ratio of the whole increase of gravity to the equatorial gravity is a constant quantity, and is equal to $\frac{5}{2}$ of the ratio of the centrifugal force to the force of gravity at the equator. Hence by ascertaining the difference between the polar and equatorial gravity, or, which is the same thing, the progressive increase in the force of gravity in going from the equator towards the pole, the ellipticity of the earth is at once determined.

It is proved in mechanics that the forces of gravity, at any two stations on the earth's surface are proportional to the lengths of the seconds Pendulum at those stations, or to the squares of the number of vibrations made by the same pendulum in any given time, one solar day for instance. Here is at once an easy means of determining the variations in the force of gravity; and the solution of the problem of the earth's ellipticity is reduced to the measure of the length of the seconds pendulum at a

* Sir G Everest proposed to employ only the Pendulum of an astronomical clock, but this method is objectionable, as the Pendulum cannot be said to be acted on solely by gravity.

† The ellipticity or compression, as it is sometimes called, is the fraction whose numerator is the difference between the polar and equatorial semi-diameters, and the denominator is the equatorial semi-diameter.

number of points on the earth's surface, or, as has been most generally done, to the observation of the number of oscillations made by the same pendulum in a mean solar day.

This theory, however, supposes the pendulum to be a "simple pendulum," that is, to consist of a material point suspended by a string without weight, which is, of course a practical impossibility; but as it is always possible to calculate the length of the simple pendulum which would vibrate in the same time as a given compound pendulum, the latter may be used for precisely the same purposes as the former.

Beside this, there are several other conditions supposed to hold good, which in practice are never attained, viz., the arc of vibration has been assumed to be indefinitely small, the length of the pendulum to be constant, *i. e*, unaffected by temperature, and the oscillations made in vacuo and at the level of the sea. Corrections have therefore to be computed and applied to the observations, for each of these assumptions.

The time of vibration* in a circular arc is expressed in terms of the length of the pendulum, the force of gravity, and a series of ascending powers of the arc of vibration. The arc is always small, but still not so small that the terms depending on it can be wholly neglected; the first term, however, of the series is all that is ever appreciable in practice. Again, the observations are generally continued for a considerable time, and the change in the arc of vibration has to be taken into account. It has been shown mathematically, on a certain supposition regarding the resistance of the air, and found to be the case practically, that the arc decreases in a geometric ratio, whilst the times increase in an arithmetic ratio, and on this principle the correction † to the observed time of oscillation is computed.

* $$t = \pi\sqrt{\frac{l}{g}}\left\{1 + \left(\frac{1}{2}\right)^2 \sin^2\frac{\alpha}{2} + \left(\frac{1.3}{2.4}\right)^2\left(\sin^2\frac{\alpha}{2}\right)^2 + \ldots \ldots \left(\frac{1.3.5.\;(2n-1)}{2.4.6.\ldots\;2n}\right)^2\left(\sin^2\frac{\alpha}{2}\right)^n\right\}$$

in which t = time of one oscillation.

π = semi-circumference of a circle whose radius is unity.

l = length of the pendulum.

g = force of gravity.

α = arc of semi-vibration.

† The formula for this correction is

$$n.\frac{M.}{32}\frac{\sin(A+a)\sin(A-a)}{\log\sin A - \log\sin a} \text{ in which}$$

n = number of oscillations made in a day; M = logmic modulus = 0·4342945; A the *initial* and a the final semi-arcs of vibration. Correction always additive.

Secondly, a correction must be applied for the temperature of the pendulum: a change of temperature will, of course, by altering the length of the pendulum, affect the time of its vibration. This correction* must be determined experimentally. Captain Kater immersed his pendulum in fluids of different temperatures, and measured with a micrometric arrangement the alterations in its length. Captain (now General) Sabine observed the change in the number of vibrations made by a pendulum in different temperatures. This is the most direct method of obtaining the correction undoubtedly, but everything depends on the perfect compensation of the clock pendulum with which it is compared.

Thirdly, the formula is only true for observations in a vacuum, and as observations have generally been made in air, or at all events only in a partial vacuum, the effect of the air has to be taken into account. This effect is to diminish the weight of the pendulum by the weight of the air displaced, or to diminish the apparent force of gravity in the same proportion. In the very large majority of observations, the correction has been computed on this consideration solely; but Bessel demonstrated in 1828† that this correction was insufficient, inasmuch as a portion of the surrounding air was set in motion by, and moved with, the pendulum so as to become part of the moving mass. The correction for this can only be determined practically, as by swinging the pendulum in "media" of different densities. It depends chiefly on the form of the pendulum. As this correction "reduction to a vacuum" or "buoyancy correction" as it is called, depends also on the state of the

* According to Kater's method—if τ be the standard temperature which is generally taken as 62° Fahrenheit; t the observed temperature of the pendulum; f its factor of expansion for 1° Fahrenheit, then correction $= \frac{1}{2} n. f. (t - \tau)$. positive when $t > \tau$.

† This circumstance was most clearly pointed out by the Chevalier du Buat in 1786, who made a number of experiments with pendulums formed of different substances, but his researches, which created a great sensation at the time, appear to have been completely lost sight of, and to have been unknown even to Borda who was conducting his experiments, little more than ten years after the publication of Du Buat's results.

The *true* correction for buoyancy Mr. Baily has shown to be (Phil. Trans. 1832)

$C \times \frac{\beta}{1 + \cdot 0023\,(t - 32^\circ)}$ where β is the height of Barometer, and t, the temperature during the interval of observation. C is a *constant* for the *same pendulum*, and is determined from the formula $C = \frac{N'' - N'}{\beta' - \beta''}\,[1 + \cdot 0023\,(t^\circ - 32^\circ)]$ in which N' is the number of vibrations in a mean solar day, β' and t' the barometer and thermometer readings, *in air*; and N'', β'', t'', the same quantities in a *highly rarified medium*, $t^\circ = \frac{1}{2}(t' + t'')$.

atmosphere, it is necessary for its calculation, to record the readings of the barometer, when the observations are taken in air.

The last correction is for the height of the station of observation above the mean sea level. The force of gravity varying inversely as the square of the distance from the earth's centre, a pendulum swung at a certain elevation above the sea, will make fewer oscillations in a day than at the level of the sea, and a correction has to be added on this account. Dr. Young, however, demonstrated that the correction computed on this consideration alone, was too large, as it neglected the attraction of the elevated mass itself, and he showed how this might be approximately allowed for.*

The general principle followed in determining the length of the seconds pendulum, is to observe the number of vibrations made by a pendulum of known length, in a mean solar day: then the length of the seconds pendulum is found by multiplying the length of the given pendulum, by the square of the number of its vibrations in a day, and dividing by the square of the number of seconds in a day.

The number of vibrations is generally determined by the method of coincidences. The detached pendulum is placed in front of a good clock, and adjusted to such a length as to gain or lose, (the latter generally,) two beats upon the clock in some convenient time, 5 to 10 minutes. Suppose the pendulums to be started together, then the longer one of the two will be left behind by the other, the distance between them continually increasing, until at length they will be at opposite extremities of their arcs of vibration at the same moment: the longer pendulum has now lost one oscillation on the shorter one, and both are apparently going at the same rate, but in opposite directions; after a short time they will begin to approach each other, the distance between them gradually diminishing, until they both appear to coincide. It is clear that between two consecutive coincidences the longer pendulum will have lost two oscillations on the shorter one. Hence all that is requisite in practice, is to observe as accurately as possible the intervals between

* This correction is given by the formula $\frac{n}{r} h x$, where n denotes the number of oscillations in a mean solar day, r the radius of the earth at the given station, h the height of the station above the mean level of the sea: x is an unknown quantity determinable from theory, on the assumption that the mean density of the earth is 5·5 and that of the surface 2·5. Dr. Young (Phil. Transactions, 1819) showed that the correction for a station on a tract of *table* land would be reduced by $\frac{1}{3}$rd or that the correction $= \frac{2}{3} n h$.

the successive coincidences; the number of vibrations made by the clock pendulum is determined by observations of the sun or stars, and then the number made by the detached pendulum is computed by simple proportion.*

The first pendulum observation of which any account is preserved are those made by Picard at Paris, and Uranienburg (Tycho Brahe's observatory) and those by Richer at Cayenne in 1672. These last observations are said to have attracted Newton's attention, as they proved the variation in the length of the seconds pendulum in different latitudes, and it is generally stated that Richer made the discovery by accident. But it appears from Picard's address to the French academy in 1671, that a variation had been already observed, and it is probable that Richer's mission was undertaken partly with a view to throw light on the subject. Picard stated that "from observations made at London, Paris, and Bologna, it would seem as if the seconds pendulum required to be shortened in approaching the equator, but that on the other hand, he is not sufficiently convinced of the accuracy of those measurements, because, at the Hague, the length of the seconds pendulum was found to be quite the same as at Paris, notwithstanding the difference of latitude."†

Near the end of the 18th century, Borda made his celebrated experiments for determining the length of the seconds pendulum at Paris. His apparatus, which is named after him, consisted of a spherical ball of platinum attached by grease to a brass cap which had been truly ground, so as to fit it perfectly. The object of this attachment was to enable the observer to turn the ball round in the cap at pleasure, so as to destroy the effects of unequal density in different parts of it. A fine wire carrying the cap was fastened to the lower end of a small cylinder, passing through the knife edge, which carried on its upper end a small moveable weight, by adjusting which, the knife edge and cylinder could be made to vibrate independently in the same time as the pendulum, so that their effect might be neglected in computing the length of the simple pendulum. When in use, the knife edge

* If r = daily rate of the clock, and I the mean interval of the coincidences, then the number of oscillations made by the pendulum in a day = $\dot{n}$

$$n = \frac{I-2}{I}(86400 \pm r)$$ the lower sign is to be used when the clock is *losing*.

† Cosmos, Vol. IV., page 25, Sabine's translation.

rested upon a steel plate. The number of vibrations per diem, were ascertained by means of a clock, but Borda made a great improvement on the old method of *counting* the coincidences. He fixed a straight edge vertically, so as to coincide with the pendulum wire at rest, when seen through a telescope placed opposite. A cross was made on the bob of the clock pendulum, and the observation consisted in noting the times when the wire and cross disappeared together behind the edge. After a series of coincidences had been observed, the length of the pendulum was measured by means of a horizontal steel plate, which was screwed up from below, so as just to touch the ball: then the pendulum was removed, and a bar, whose length had been carefully compared with a standard, inserted in its place. The bar had a T head, of which the lower surface rested on the upper steel plate, and a graduated rod, sliding on the bar, was adjusted to contact with the lower plate. The diameter of the platinum ball was then measured by means of the same slider, by placing it on the steel plate for the purpose; the brass cap and wire were then weighed. The apparatus was enclosed in a glass case, and the temperature was carefully recorded. All necessary corrections were applied, excepting the true one for buoyancy. The whole process, which required very great delicacy, had to be repeated, and the length of the corresponding simple pendulum computed after each series of observations. Borda's pendulum was about 12 feet in length.

His method was followed by M. M. Arago, Biot, and Chaix, at Formentera, the southernmost station of the French arc, with this exception that they used a pendulum of only 3 feet in length. These observations were extended by Biot in 1817 to Leith, and Unst in the Shetlands, and in conjunction with M. Mathieu, he observed at Dunkirk, Paris, Clermont, Bordeaux, and Figeac. From these operations, Biot deduced an ellipticity of $\frac{1}{304}$.

In about 1809, Captain Warren made some observations at the Madras observatory with a pendulum formed of a leaden ball suspended by a fibre made from the plantain leaf. The vibrations were counted and an assistant noted the times, from an astronomical clock. In order to measure its length, he attached some glass plates to a wall, and set off on them a scale, transferred from Colonel Lambton's scale; the length was then measured by a pair of beam compasses. The length of the

seconds pendulum was found to be 39 0263 inches of this scale *in air*.

In 1818, Captain Kater published his determination of the length of the seconds pendulum in London at Mr. Browne's house, Portland Place, taken for the purpose of fixing the standard of English measures. His method was founded on the dynamical theorem due to Huyghens, that the centre of oscillation, and axis of suspension, are reciprocal in the same body; that is, if the body be suspended at its centre of oscillation, the former axis of suspension will pass through the new centre of oscillation, and the body will vibrate in the same time as before. The distance from the axis of suspension to the point called centre of oscillation, is equal to the length of the simple pendulum.

Captain Kater's pendulum consisted of a bar of plate brass 16 inches broad and $\frac{1}{8}$th of an inch thick: two knife edges of the hardest steel, attached to solid pieces of brass, were fixed to the bar at a distance of rather more than 39 inches from each other; when the pendulum was in use, these knife edges rested on horizontal planes of agate. At one end of the bar, immediately below the knife edge, was a large flat brass bob firmly soldered to it: and on the bar, between the knife edges, were two sliding weights. The plan of operations was to observe the number of vibrations per diem, made by the pendulum when suspended, first, by one knife edge, and then, by the other; and if these numbers were not identical, to make them so, by means of the sliding weights. The distance between the knife edges, that is, the length of the corresponding simple pendulum, was then measured by a micrometric arrangement. The method of observing the number of vibrations was as follows: to each extremity of the pendulum, a light deal tail-piece, well blackened, was attached; and on the bob of the clock pendulum a white paper disc, equal in diameter to the breadth of the tail-piece, was fastened; the detached pendulum was now placed in front of the clock, and both pendulums being at rest, a telescope was aligned, so that the blackened tail-piece exactly covered the paper disc. The telescope was also fitted with a diaphragm, consisting of two perpendicular cheeks which could be adjusted so as to become tangents to the disc. Now, if both pendulums be set in motion, the detached pendulum vibrating slower than the clock one, the tail-piece will be seen to pass across the diaphragm, followed by the

white disc; at each succeeding vibration the disc follows closer and closer, first touching it, and at last becoming completely eclipsed by it. The exact time of this event, called a "disappearance," is noted; after a few more vibrations, the disc will re-appear *preceding* the tail-piece; the time of this event, called the "re-appearance," is also noted; and the mean of the disappearance and re-appearance, is taken as the true time of coincidence. It is immaterial in this method of observation, whether the detached pendulum vibrates faster or slower than the clock pendulum, but it is a *sine quâ non* that its arc of vibration be less. The result, introducing all corrections, except the true one for buoyancy, was 39·13929 inches, which is still the received length, although General Sabine in 1831, showed, by swinging the pendulum in air and in vacuo, that the buoyancy correction was different, according as the heavy weight was above, or below, the plane of suspension.

Captain Kater, in the following year, 1818, made a series of experiments at the principal stations of the English Survey, from Shanklin in the Isle of Wight, to Unst in the Shetlands. He used in these observations a pendulum of a different pattern, known as "Kater's invariable pendulum." With it, it is not possible, nor was it intended, to determine the length of the seconds' pendulum, but it is essentially a differential instrument, and is used for measuring the differences in the number of vibrations at different stations. With these differences, if at any one station the length of the seconds' pendulum has been already determined, the corresponding lengths at the other stations can be ascertained. The invariable pendulum is of the same dimensions as the convertible one, but is without the second knife edge, and tail-piece, and the sliding weights. The mode of observation is exactly the same. Captain Kater deduced values of the ellipticity, from consecutive pairs of stations; he considered $\frac{1}{304}$ as a probable value (the same as M. Biot's); but he remarks on the difficulty of deriving a satisfactory determination, unless the extreme stations comprise an arc of sufficient extent to render the effects of irregular local attraction insensible.

In 1821-22, some very good observations were made by Mr. Goldingham, at Madras, and afterwards at a small island called Pulo Gaunsah Lout, lying nearly on the equator in East Longitude 98° 50′. The pendulum used was an invariable one, and observations were first taken

with it in London, by Captain Kater. From the observations at Madras and London Mr. Goldingham deduced an ellipticity of $\frac{1}{297}$.

Captain Basil Hall, assisted by Captain (then Lieutenant) Henry Foster, made a series of experiments with an invariable pendulum in 1820-23, at Galapagos, San Blas (Mexico), Rio Janeiro, and London (Mr. Browne's house). Comparing the results at each of his own stations, with each of Captain Kater's, he deduced ellipticities of $\frac{1}{285}$, $\frac{1}{314}$, and $\frac{1}{302}$.

In 1822, Sir Thomas Brisbane took with him to Paramatta (near Sydney), an invariable pendulum that had previously been swung in London, at Mr. Browne's house. He deduced ellipticities of $\frac{1}{296}$ and $\frac{1}{304}$, comparing his observations with those of Kater in London and at Unst.

In 1817, the French Government fitted out a scientific expedition under the command of Captain Freycinet, who was furnished with three invariable brass pendulums, one of which was similar to Captain Kater's pattern, and the other two had solid cylindrical rods instead of a flat bar. He had also a fourth pendulum, with a wooden rod formed of two plates of deal firmly clamped together. Instead of a clock he used an astronomical counter, ("compteur astronomique,") whose beats could be adjusted to synchronism with those of the pendulum. The counter had a dial, which showed hours, minutes, and seconds, so that by comparing the time shown by this "compteur" with that of a chronometer, he obtained the number of vibrations made by the pendulum in a certain interval, generally an hour or 40 minutes. The pendulums were first swung at Paris, and afterwards at Rio Janeiro, Mauritius, Guam (one of the Ladrone Islands), Mowi (one of the Sandwich Isles), Cape of Good Hope, Port Jackson, Rawak (an island under the line, north of New Guinea) and Malouine or Falkland Isles. Rejecting the determinations at the Mauritius, Guam and Mowi, as they appeared affected to a remarkable degree by local influences, Captain Freycinet deduced an ellipticity of $\frac{1}{289}$ from all four pendulums.

On the return of Captain Freycinet, the French Government sent out another expedition under Captain Duperry. He was supplied with two of Captain Freycinet's brass pendulums, viz., one with a cylindrical rod, and the one on Kater's principle. He observed at six

stations, viz., Ascension, Mauritius, Port Jackson, Falkland Isles, Toulon, and Paris. In deducing the ellipticity he combined his results with those of Freycinet only, and obtained values varying from $\frac{1}{266}$ to $\frac{1}{290}$.

During Ross' voyage to Baffin's Bay in 1818, some observations were taken at Brassa, in the Shetlands, and at Hare Island, with a clock fitted with an invariable pendulum vibrating on a knife edge, which rested on hollow agate cylinders. Observations were repeated at these stations, and a further set taken at Melville Island, on Captain Parry's first voyage to the North Pole in 1819-20. Captain Sabine conducted both these experiments, using the same instruments.

In 1822, the English Government sent out an expedition under Captain, now General, Sabine, for the purpose of extending the enquiry commenced by Captain Kater; for both Kater and Biot had come to the conclusion, from a discussion of their experiments, that no decisive result of the earth's ellipticity could be obtained from them, on account of the smallness of the comprised arc, and the variations of local density. Captain Sabine visited thirteen stations between Bahia, S. Lat. 12° 59′ to Spitzbergen N. Lat. 79° 50′. He had with him three pendulums of Kater's invariable pattern, which were all swung at each station. Besides these he had the two clocks and attached pendulums which he had already used on his arctic voyages. His method of observation was similar to Captain Kater's; all the pendulums were swung in London at Mr. Browne's house, both before and after the expedition.

The ellipticity deduced from the experiments at Captain Sabine's stations was $\frac{1}{288.4}$, from the same combined with Kater's $\frac{1}{289.5}$, and combined again with Biot's $\frac{1}{288.6}$, and from a general combination of all of these, $\frac{1}{289.1}$. The observations of the *detached* pendulums only were used in these determinations; for though the clock pendulums gave closely coinciding values of ellipticity, still being acted on by other forces than gravity, their results are less reliable, and are only valuable in so far as they afford an independent corroboration of the other results. Captain Sabine was not at first aware of the strict expression for the reduction to a vacuum, but after the publication of Bessel's observations in 1828, he had an apparatus specially constructed, and ascertained the proper correction practically, by swinging his pendulums in air, and in vacuo.

The error from this cause, however, proved to be trifling, owing to his observations being strictly differential, so that only the differences between the corrections by the old and new formulæ entered.

The most widely differing buoyancy corrections at any of his or Captain Kater's stations of observation, computed by the old formula were + 5·75 vibrations at Sierra Leone and + 6·27 vibrations at Spitzbergen, in a mean solar day. These corrections, multiplied by the proper factor, 1·65, to reduce them to the new formula became + 9·52 and + 10·38 vibrations, so that the number of vibrations in a mean solar day at Sierra Leone required to be increased by (9·52 − 5·75) 3·77 and at Spitzbergen by (10·38 − 6·27) 4·11 vibrations. But the acceleration between the stations would only be *increased* by the difference between these numbers, or by 0·44 vibrations. It so happened, however that even this difference was too large, for in the deduction of the temperature correction, the old buoyancy formula had of course been used; on applying a correction on this account, the above difference required to be *reduced* by 0·36 vibrations, so that the whole error on the acceleration of the pendulum between Sierra Leone and Spitzbergen was only + ·08 vibrations.

Captain Sabine subsequently determined the difference in the number of vibrations made by an invariable pendulum between London and Paris, London and Greenwich, and London and Attona. He also determined the true buoyancy correction for Kater's convertible pendulum.

(To be continued.)

No. CXXXIX.

DRAINAGE OF MADRAS.
(2nd Paper.)

Abridged from a Report on a Project for the Drainage of the Town of Madras. BY CAPT. HECTOR TULLOCH, R.E.

Description of the Project.—It is proposed to drain Madras from the south to the north—to separate the sewage from the rain-water—to carry the former by sewers of small capacity to *one* central spot, north of, but near, the Madras Railway, and in the neighbourhood of the village of Coorookoopett—to lift it there by steam pumps—and, according as Government may decide, either to discharge it by an outfall sewer into the sea at a point two miles north of the Railway, or to utilize it on some thousands of acres of waste land lying to the north-west of Madras.

In order to render the description of the Project clear, I shall, for the present, defer the consideration of the proposition to utilize the sewage for agricultural purposes, and treat the subject of drainage as if it were necessary to take the sewage away from Madras altogether.

The first point to settle in every project for drainage is the locality of the ultimate outfall for the sewage. Everything hinges on this. At present the sewage of the town, as before mentioned, is discharged partly into the Cooum, partly into the canal, and partly into the sea; and these are all the outfalls available for Madras.

It is unnecessary for me to dwell on the present disgusting state of the Cooum or on that of the canal. To say that they are mere cesspools, from which the sewage cannot possibly escape, is to bring the subject

with sufficient clearness even to the minds of those who have never visited Madras. It should be an indispensable condition of every project for draining the town, that the Cooum and the canal should not be converted into sewage reservoirs. Until this is acted upon, all attempts to render Madras healthy must necessarily be only partially successful.

The only outfall, then, left for consideration, is the sea. The abominable stench from the mouth of the sewer at the north-east angle of the Fort, which drains a portion of Black Town only, is convincing evidence that it is not sufficient merely to discharge the sewage into the sea. No description can convey to the minds of those who have never lived within the influence of the smell from this sewer, its overpowering offensiveness while the outlet is open. The Fort would hardly be habitable from October to February, or while the north-east winds prevail, if this outlet were kept open during the whole day. Fortunately, the sewer is large enough to hold all the sewage which flows into it, for a day or two, so that it is unnecessary to open the mouth except for about a couple of hours during the night. This is done, too, at a time when the wind is blowing from the west, in order that the smell may be driven out to sea.

In some instances in England, no nuisance arises from the outfalls of sewers being placed on the coast and opposite to towns. But this is due to causes which do not prevail in Madras. In England, the tides rise and fall considerably. In London, the difference between low and high tide is 20 feet—in Liverpool, it is 32 feet—in the Bristol Channel, as much as 47 feet. The velocity of the ebb stream, or that which conveys the sewage away from the coast is, under these circumstances, very great. But in Madras, the tides rise and fall three feet only, and the water is exceedingly shallow. The consequence is, that the velocity of the ebb stream is trifling, and the sewage keeps floating by the coast instead of being carried out to sea at once. The prevailing currents, too, for 10 months in the year, follow the line of the coast, *i. e.*, run north and south. Sewage, therefore, discharged opposite the Fort, flows directly in front of Black Town or Triplicane, the two most important, because the most densely populated, neighbourhoods of Madras.

The nuisance at present from the drain near the Fort is as nothing compared with the nuisance which would ensue, if the main outfall for the drainage of the entire town were situated in the same locality. Under the present imperfect arrangements for drainage, the quantity of sewage which

ultimately reaches the sea is small, and it is sufficient if the mouth of the main discharging sewer is opened occasionally. But under a complete system of water-tight sewers, and street and house pipe-drains, the quantity of sewage would be considerable, and it would be impossible to pond it up for many hours together without incurring great expense. The line of coast, too, for a quarter of a mile or so on either side of the outfall, would be so covered with filth of every description, that the sea breeze, instead of being, what it now is, a great source of health to the inhabitants of Madras, would be deprived of all those pleasant associations which we at present connect with it. No outfall so situated as to contaminate our sea breeze should be permitted.

If this is granted, it follows that no sewage should be discharged on the sea-board of Madras Proper, *i. e.*, within the limits of the inhabited strip of coast land from Royapooram in the north to St. Thomè in the south. The question, therefore, so far as the outfall only is concerned, resolves itself now into this, "Shall the sewage be carried into the sea north, or south, of Madras?"

In order to decide this satisfactorily, several points should be considered. "Is the town, with regard to its physical features, more favorably situated for a southern or for a northern outfall?" "What is the direction of the prevailing winds?" "What that of the prevailing sea current?" "What particular advantages does a northern or a southern outfall offer in itself?"

The most important of these considerations is, without doubt, that which relates to the general configuration of the ground on which the town stands. Now, it has already been explained that, practically, there is no natural line of drainage for Madras, considered as a whole. But if this point admits of dispute, then the only line of drainage, which it is possible to call such, is the valley along which the canal runs. And, certainly, although the greater part of Black Town and all Royapooram drain into the sea, yet the portion of Madras lying to the north of the Cooum, may, in some respects, be considered as two slopes of ground inclining towards the Canal. The fact, too, of the districts south of the Cooum being generally on a higher level than the valley itself, may strengthen this view—*viz.*, that there is a natural drainage line. But this very fact shows that the southern portion of Madras, if it is the higher, must be drained towards the north, *i. e.*, if the valley of the canal is taken as the drainage course.

And the northern portion cannot be drained to the south, because, in that case, the outfall into the sea must be situated somewhere between Triplicane and Black Town, which, it has already been shown, would be highly objectionable, because the sea breeze would be contaminated. The only course left to adopt then, is, to drain the whole of Madras to the north. And this is exactly what is proposed to be done. So far then as the question is affected by considerations of the natural position of the town, the advantage of the northern outfall is clear and decided.

Now, with respect to the winds, the situation of the two outfalls is about equally favorable. The prevailing winds* are those which blow between south and west, and these winds in *either* case would convey the smell of the sewage out to sea. The winds which would bring the smell into Madras, are, in the case of a northern outfall, those between N. N. E. and E. N. E., and, in the case of a southern outfall, those between S. and S. E. Both the former and the latter blow for about 80 days in the year.

With reference to the sea currents, the advantage lies decidedly with the northern outfall. The current which flows from the north southwards begins about the middle of October and ends in February, or runs for about 4½ months in the year. This current would, in the case of a northern outfall, bring the sewage in the direction of Madras, and, in the case of a southern outfall, would carry it away from Madras. The current which flows from the south northwards begins in March and ceases in August, or continues to flow for about six months. During the remainder of the year, *i. e.*, in September and the first half of October, the prevailing winds are from the south, and if, as is most probable, the currents run in the direction of the wind, this second current will have a northerly direction. Thus, for about 7½ months, the northward current would, in the case of a northern outfall, carry the sewage away from Madras, while, in the case of a southern outfall, it would bring it to Madras. There is no doubt, therefore, that, so far as the currents of the sea are concerned, the outfall should be placed to the north of Madras.

The special advantages which the northern outfall offers are very great. There are no Engineering difficulties to be overcome in the construction of the works, or to render them expensive. If the sewage were taken to the

* *Vide* "Chart showing the number of days in the year the wind blows in Madras from each point of the compass," which is given further on.

south, the outfall should be placed at least one mile south of St. Thomè, in order to prevent any nuisance to the inhabitants of this locality. This would make it necessary to carry the sewage either by a tunnel beneath the river Adyar, or by an aqueduct over it. Either of these works would cost a large sum of money. In the south, the sewage could not be utilized for agricultural purposes so judiciously as in the north, for the prevailing winds would blow the smell to the town. The lands, moreover, are not well situated, whereas, in the north, there are upwards of 20,000 acres of waste ground situated on the most favorable level possible, and in the direction from which the wind blows least often during the year. All these considerations render it advisable to adopt a northern outfall for the drainage of Madras.

Having settled this point, it next becomes necessary to decide *how far* north the sewage should be discharged. And this admits of some difference of opinion. The arrangements made in this Project are to place the outfall, *for the present*, at a point two miles north of the Railway Station. This is 1½ miles from the nearest dwellings in Royapooram. I believe no nuisance will arise from this arrangement. When the northerly current is running, the sewage will have flowed a distance of more than two miles before it comes opposite to the nearest part of Black Town. Should it, however, be found hereafter that the outfall is not far enough away to the north, I have arranged so that it may ultimately be removed to a point three miles north of the Railway. Without positive evidence that the outfall at this distance would prove a nuisance, it would not be desirable to place it higher up on the coast. The question is one of expense only, for, so far as the Engineering difficulties are concerned, it would be as easy to carry the sewage four miles to the north as to discharge it where it is now proposed to place the outfall.

Having now arranged about the direction in which Madras is to be drained and the distance from the town at which the outfall should be situated, the next question requiring an answer is, "Can the sewage be discharged into the sea simply by gravitation, *i. e.*, without lifting it at any intermediate point between the town and the outfall?" An examination of the Map of Madras,* which accompanies this paper, should convince any one that this is impossible. The present system of open drains is a practical attempt to answer this question in the affirmative. But what

* Given above p. 2.

the effect is, is known well. Hardly a single drain has sufficient fall to keep itself free from deposit, and the consequence is, that the work which the drains should do, has to be done by the scavengers of the Municipal Department, and at a tremendous cost to the people. It is, indeed, impossible to drain a place like Madras, which covers 27 square miles of country, and many parts of which, in all quarters of the town, are elevated from 3 to 6 feet only above the sea, by simple gravitation, and without raising the sewage artificially.

If this, then, be admitted, the next point to settle is, "Where shall the sewage be pumped up?" This is almost altogether a question of Engineering. If the ground were very favorable, *i. e.*, if the soil were hard and there were no water to interfere with the construction of the sewers, it might be best to take the sewage right away to a spot near its ultimate outfall on the coast, and to pump it up there at once into the sea. But this is not the case. The strata beneath the surface soil consist chiefly of sand, and water is found in almost all parts of Madras at about the sea level. It becomes, therefore, positively necessary to raise the sewage at some intermediate point. I have selected a point very near the Madras Railway, but lying to the north of it and in the neighbourhood of the village of Coorookoopett. This will necessitate the construction of a tunnel under the Railway. But a tunnel would have been necessary, even if the site for the pumps had been to the south of the Railway; for the sewage of Tondiarpett and of the neighbourhood to the north of the Railway must, in that case, have been brought to the site by a tuunel crossing the Railway. It will thus be seen that, under any circumstances, a tunnel was unavoidable. The site selected for the cesspool and pumps is situated in that quarter of the town from which the wind blows least often in the year, and it is near the lands on which it is proposed to utilize the sewage.

I have considered whether it might not be advisable to have two cesspools and two sets of pumps—one for the portion of Madras lying to the north of the Railway, and the other for that lying to the south of it. But the first cost of such an arrangement would be even greater than that of the tunnel now proposed, and the working expenses of such a system of sewerage would be nearly double that in which all the pumping work was concentrated at one point.

I trust that it has now been satisfactorily shown that Madras should be drained towards the north,—that (putting aside for the present the ques-

tion of utilizing the sewage) the best outfall is the sea,—that it will be sufficient if the outfall is placed on the coast three miles north of the Railway,—that it is not possible to drain the town by gravitation,—and that, consequently, the sewage must be pumped up at some intermediate point between the town and the ultimate outfall.

Separation of Sewage from Rain Water.—So far, this Project does not differ from the system of drainage adopted in many towns in England. I beg now to draw the attention of Government to a point which appears to me to demand the greatest consideration. In England, it is usual to have one and the same system of sewers to carry off both rain-water and sewage. I propose, however, that in Madras, sewage shall be carried away by a system of underground sewers and pipes of very small dimensions, and that rain water shall be removed by a system of open surface drains unconnected with the underground sewers and pipes. To justify such a departure from the stereotyped system of sewerage which has the sanction of European Engineers, it will be necessary that full and sufficient reasons should be given.

In designing sewerage works, the dimensions of the sewers are regulated almost entirely on considerations of rain-fall. The sewage proper forms so small a proportion of the total amount of fluid matter to be removed, that if a sewer is large enough to discharge the rain which falls on the district for the drainage of which it is constructed, it is hardly worth while to consider the small quantity of sewage which may flow into the sewer. In fact, sewers in England are constructed, *first*, for the removal of the rain-fall, and then for the removal of the sewage.* In a country, however, like England, where the rain-fall is pretty evenly distributed through all the months of the year, and where there are no extraordinary falls of rain such as we so often have in India, this principle of carrying off both rain water and sewage by one set of channels is not perhaps objectionable. It rains off and on throughout the year. Sometimes for days together there is no cessation at all. The consequence is, that the amount of water in the sewers does approximate to *some* extent to a constant quantity. In heavy rain-falls the amount is somewhat in excess of this quantity, and in light rainy weather it is somewhat below it.

But in India the conditions of rain-fall are totally different to those in

* In London the sewage proper is calculated at about $\frac{1}{8}$th of the ordinary rain-fall.—*Vide page 305 of "Neville's Hydraulics."*

England. In the first place the yearly rain-fall in India is double that of England. And while in England the supply is received in small monthly instalments all the year round, the supply in India is often received in 10 or 12 days only.

The accompanying diagram has been prepared with the view to explain the extraordinary difference between the rain-fall in England and in Madras. The first fact to which I beg to direct attention is the marked evenness of the line which represents the "mean" rain-fall in England.* The greatest difference in the quantities of rain which fall in any two months is between those which fall in April (about 1½ inches) and in November (about 3¾ inches). But even this difference amounts to only 2¼ inches. So evenly distributed is the rain-fall, that if it were said of England that the quantity of rain which falls in every month of the year is 2 inches, there would really be no great error made.

The second fact to which I would draw attention is the parallelism between the thick and thin red lines. The former shows the maximum quantity of rain that has been known to fall in England in each month of the year. It runs throughout about 2 inches above the thin line and thus indicates that the maximum quantity of rain in each month is 2 inches only more than the mean quantity.

Now, let me turn to the rain-fall in Madras, the yearly quantity (about 50 inches) being double that of London (about 25 inches). The thin blue line represents the mean rain-fall of 20 years' observations. It will be seen that in the first four months of the year there is, practically speaking, no rain at all—that in the next 5 months the rain-fall is only slightly in excess of that of England—but that in the months of October, November and December, it is considerably in excess of it. Now, if sewers are to be constructed for the removal of rain water, it is very evident that in Madras they must be large enough to discharge the rain-fall in the months of October and November, when the heaviest quantity of rain descends. Suppose that the dimensions of the sewers in Madras are regulated by comparison of the mean monthly rain-falls in London and Madras. Then, the mean rain-fall in Madras in October (about 13 inches) being more than three times the mean rain-fall in London in November (about 4 inches), it is evident that the sewers must have three times the discharging capacity. A single

* *Vide* Page 311 of "Neville on Hydraulics."

mile of sewers laid down on this principle would cost more than the entire project now submitted to Government.

The difference between the maximum monthly rain-falls in Madras and in England, is even still greater than that between the mean monthly rain-falls in the two places. The maximum quantity which has fallen in one month in England is, as shown by the thick red line, nearly 6 inches. But the maximum in Madras is, as shown by the green line, nearly 38 inches, or upwards of six times the maximum of England.

Together with the mean and maximum monthly rain-falls in the two countries, I have projected on the accompanying diagram the monthly rain-falls in Madras of some of the most interesting years. From these it will be seen that it is far from an unusual occurrence to have upwards of 20 inches of rain in a single month of the year.

If we compare the *daily* rain-fall in England and in Madras, the difference becomes still more striking. The following are the greatest daily rain-falls in England of which I can find any record :—

Locality.	Date.	Rain-fall in 24 hours.	Remarks.
		Inches.	
Little Bridy, Dorsetshire,	July, 1858	2·06	*Vide* page 332 of "Beardmore's Manual of Hydrology."
Oxford, . . .	July, 1853	1 82	*Vide* page 333, *Ibid.*
Wandsworth, .	12th June, 1859	2·17	*Vide* page 293 of "Neville's Hydraulics." This fell in two hours.
Manchester, .	7th Aug., 1859	1·849	Do. do.
Southampton, .	26th Sept., 1859	2·05	Do. do. This fell in 2¼ hours.
Truro, . . .	25th Oct., 1859	2·4	Do. do.
Holborn, . . .	1st Aug., 1846	4·00	Do. do. These quantities are stated to have fallen in one hour.
Highgate, . . .	Do.	3·5	
Greenwich, . .	Do.	·95	

The following is a table of some of the heavy daily rain-falls in Madras in the years from 1822 to 1857 :—

Date.	Rain-fall in 24 hours.	Remarks.
	Inches.	
4th November, 1822	7·88	
29th October, 1825	8·87	
9th May, 1827	12·08	
27th November, „	7·77	
31st October, 1836	7·50	This fell in the night only.
20th November, „	9·65	* It appears to have commenced raining on the 18th October. Up to 6 A. M. on the 20th, however, only 3½ inches fell. It then progressed very steadily for about 20 hours, till the maximum rate of 2½ inches per hour was attained: after which it gradually decreased again till at the expiration of about another 12 hours when the monsoon was over. In this storm, Madras received, in 24 hours, i. e., from 10 A. M. on the 20th to 10 A. M. on the 21st, about as much rain as falls in London during the whole year.
27th December, 1845	7·20	
21st October, 1846	20·58*	
4th May, 1851	11·45	
4th November, „	7·90	
20th November, 1856	6·22	This fell in 5 hours.
24th October, 1857	18·04	Before sunrise 5·83 inches—before sunset 12·21 inches.

It will thus be seen that while 4 inches are the utmost that has been recorded to have fallen in England during the day, upwards of 20 inches have been known to fall in Madras in the same period of time. How could Madras afford to pay for sewers constructed to discharge five times the quantity of water which the London sewers discharge?

It will naturally be asked, "If the sewers are not to carry away the rain water, how is it to be got rid of?" The answer is—"by open channels." I propose, however, at first, to make use of the existing large drains as the outlets for storms. This will, no doubt, cause surprise to many, considering how much the present drains have been abused. It is well known, in drainage engineering, that when the quantity of water is great, the form of the sewer is of little consequence. Whether it has a rectangular section or an oval section, the velocity is still sufficient for all possible purposes. Now, the section of the Madras drains is certainly very far from faultless. Nevertheless for storm waters they will answer admirably. When Madras can better afford it, it will be time to reconstruct these channels, but having

them now at hand, I am decidedly of opinion that they should be used. The drains which I propose to keep are not, of course, the open *street* drains in all parts of Madras, but the few large underground and open channels which discharge immediately into the sea, the Cooum, or the canal. All the street drains should be taken up, for the bricks of which they are constructed are of the worst possible kind and so saturated with liquid filth, that every effort to cleanse the town without the removal of these drains will be ineffectual. At present, all that would be necessary would be to re-place these drains with broken granite, down which the rain water would flow until it ultimately entered, as it now does, one of the large outlet drains. The Municipal Commissioners, who spend yearly about 20,000 rupees in new drains, would have that sum available for this work, inasmuch as no new drains would be required in the town if this Project were carried out. Ultimately it might become necessary to have open channels of stone set in mortar, similar to those in use in England.

On this question of the separation of rain-water from sewage, I understand that it will be urged by the advocates of universal dry conservancy against me—"So, after all, your sewers will not get rid of the rain water." But these gentlemen forget that this argument tells, if possible, much more against them than against me. For, at all events, I do propose to dispose of all liquid refuse *except* storm waters, whereas the advocates of universal dry conservancy propose to get rid of 100th part only of the liquid refuse, and moreover of none of the storm water. If, therefore, it is necessary for the advocates of sewers, so also must it be necessary for the advocates of universal dry conservancy, to dispose of storm waters. It is no use to find fault with a sewer system from which storm waters are excluded, unless some mode of removing these storm waters, better than that suggested by me, is put forth by the objectors. All that I maintain is, that it will be unadvisable to adopt the European system of sewerage in its entirety in Madras, simply because, if rain water is to run in the same channel with sewage, the discharging capacity of the channel in Madras must be *four* times what it is in London for the same area to be drained—that sewers laid down on this principle will be perfectly useless for eleven months in the year—and that the cost of them will ruin the Municipality.

Details of Sewers.—The general system of sewers proposed to be laid down will best be understood by reference to the map of Madras given

above (p. 2), from an inspection of which the exact course of each sewer can be seen.

All the sewers proposed to be laid down in this Project are to be egg-shaped,—the diameter of the upper arch being double that of the invert. As it is now generally acknowledged by the Engineering profession that this is the best form for sewers where the quantity of sewage is constantly varying, it is unnecessary for me to dwell on the advantages of adopting it for the Madras sewers.

The formula by which the dimensions and slopes of the sewers have been calculated is the one used by Mr. Beardmore in his work, "Manual of Hydrology;"

$$v = 55 \sqrt{2 h f},$$

in which v is the velocity of the stream in feet per minute—h the hydraulic mean depth in feet—and f the fall in feet per mile.

A single example will best explain how the dimensions of the sewers for the Main Line have been decided on.

It has been assumed that the quantity of water used per head of the population, may ultimately be as high as twenty gallons per diem. Excepting the western portion of the neighbourhood lying to the north of the Railway, the population of which is about 54,000, the whole of Madras will be drained through the Main Sewer. If the population of Madras be taken at 428,000, the total quantity of water flowing into the cesspool in 24 hours through the Main Sewer will be $(428{,}000 - 54{,}000) \times 20$ gallons $= 7{,}480{,}000$ gallons, or 1,196,800 cubic feet. Assume that half this quantity, or 598,400 cubic feet, will run off in 8 hours, the period of maximum daily flow, then the quantity to be discharged every minute by the Main Sewer will be $\frac{598{,}400 \text{ cubic feet}}{8 \text{ hours} \times 60 \text{ minutes}} =$ (say) 1,247 cubic feet.

Now, a sewer 6 feet by 4 feet, laid at a slope of 2 feet per mile, will discharge upwards of 1,650 cubic feet per second, assuming the co-efficient of friction to be ·75. The velocity of the stream would be about 18 inches per second. Allowing a large margin for prospective population, I think if the Main Sewer at its junction with the cesspool is 6 feet by 4 feet and laid at an inclination of 2 feet per mile, it will be quite large enough. I very much doubt if the Main Sewer will for many years be more than one-third full. But it is safer to make the sewers too large than too small.

As it is not intended that the sewers proposed to be laid down according to this Project shall remove rain water, it is necessary that the principles

on which the general system of drainage have been designed should be explained. In order to utilize to the utmost the natural slopes of the ground for the street drains, I have run the Main and Branch Sewers, as a general rule, along the valley lines of each neighbourhood. To ascertain, however, *at what depth* they should be placed below ground, I commenced laying down the street drains from the highest points in each district, and working down to the Main and Branch Sewers. The slopes given to the street drains, which will be earthenware pipes of 6 and 9 inches in diameter, are such as to admit of the sewage flowing through them at the velocity of at least 3 feet per second. The 6-inch pipes at the highest points in each district will be laid at an inclination of from 1 in 150 to 1 in 100. and, in those streets which are situated nearer the valleys, the slopes of the drains will be much greater than this. The slopes of the 9-inch pipes range from 1 in 250 to 1 in 170. In fact, the levels at which the sewers are put below ground are such as to admit of the pipe-drains in all the streets being laid at such inclinations as will generally enable them to keep themselves clear of deposit.

On the accompanying plan of Black Town, the complete system of sewers and pipes for this district is shown. The general principles of drainage which I have adopted will be better understood by an examination of this plan than by any written explanation on my part.

I have given the greatest consideration to the question of slope. Had the strata on which Madras stands, been favorable to the construction of sewers at a great depth, I should have laid them at a much greater slope than that on which they are placed at present, but these strata consist almost everywhere of sand or clay, and water is found in all parts at about the level of the datum line. The building of the sewers, therefore, if they were put very deep below the surface, would be difficult, and attended with considerable expense. I have preferred to adopt a medium slope, and propose to turn the abundance of water to use in flushing the sewers.

The Main Sewer at its head will be 3 feet by 2 feet, and laid at an inclination of 4 feet per mile, and at its termination it will be 6 feet by 4 feet with an inclination of 2 feet per mile. It will start at about the level of the datum line and will terminate at the level of 16·25 feet below the datum line. Where each Branch Sewer joins the Main, the dimensions of the latter will be increased, and as the Main Sewer becomes larger the slope will be gradually decreased.

All the Branch Sewers, without exception, are to be 3 feet by 2 feet, and to be laid at an inclination of 4 feet per mile. They are considerably larger than they need be, so far as the quantity of sewage which they will have to convey away is concerned, but it would be difficult to cleanse a sewer of smaller dimensions thoroughly. I had thought at one time of using large earthenware pipe-drains for the branch sewers, but the expense of these would be as great as that of the sewers now proposed.

The entire system of sewers is designed to secure one uniform velocity (about 18 inches per second) for the sewage throughout its flow, from the beginning to the end of each sewer.

All junctions between the sewers will be effected by Bell-mouth Junctions.

As fast as the sewage arrives at the end of the Main Sewer, it will be pumped up by means of steam pumps to a height of 10 feet above the datum line, and it will immediately enter the Outfall Sewer, which will carry it to the sea. The position of this Outfall Sewer is shown in the map of Madras, above given. Its dimensions are the same as those of the Main Sewer at its junction with the cesspool, but while the inclination of the latter is 2 feet per mile, that of the Outfall Sewer is 3 feet per mile. This extra fall has been given with the view to secure a greater velocity for the flow of the sewage, as there will not be those facilities for flushing the Outfall Sewer which exist for the other sewers.

A great portion of the Outfall Sewer will run above the surface of the ground, but the line which has been adopted for it is very favorable, and no impediments to traffic will in any way be caused by this work.

The Outfall into the sea has been designed with great care. It will be built of solid ashlar masonry, standing on a groyne of granite boulders run out 200 feet into the sea. The invert of the sewer will be on a level with low water-mark. I think the Outfall will be found strong enough to resist the action of the surf.

Every sewer will be thoroughly ventilated through charcoal disinfectors. The ventilators will be placed at about 100 yards apart, and will be so arranged that dust or gravel falling through them from the roads will be intercepted and prevented from entering the sewers. The dirt can be removed at stated times without interfering with the action of the ventilator.

In connection with every ventilator there will be either a man-hole or

side entrance leading into the sewer, so that, when necessary, men may easily enter the sewers to clean or inspect them.

The St. Thomè and Outfall Sewers being above the level at which water is found, arrangements cannot be made for collecting water below ground for flushing them; but for all the other sewers there will be a flushing apparatus in connection with every ventilator and man-hole or side entrance, as the case may be. The flushing arrangements will, therefore, occur at intervals of about 100 yards apart, and it is expected that each apparatus will cleanse the sewer thoroughly up to that point in it where the next apparatus occurs.

The accompanying plan represents a flushing reservoir in connection with a man-hole and ventilator. The foul air from the sewer will travel up the man-hole shaft—pass through the charcoal in the box *a*, the bottom and top of which will be made of iron wire netting—and will escape, first through the opening *b*, and then through the ventilator *g*, to the open air. Any gravel or dust falling through the ventilator will be intercepted in the chamber *c*, and when it is necessary to remove the rubbish, the trap door *d* will be opened, the box *a* pushed into the recess *e*, and the chamber *c* will be cleansed through the door *f*, on the opening of which the rubbish will fall out and be received in a basket held at the mouth of the entrance. When the rubbish has been removed, the door *f* will be closed, and the box *a* will be pulled out of the recess and replaced in its original position over the man-hole shaft. Thus, all the foul air that escapes from the sewer will be made be pass through the charcoal which, it is expected, will in a great measure, disinfect it.

At the bottom of the man-hole shaft there will be a masonry reservoir (capable of holding about 350 gallons of water), which will be fed from a filtering well. The reservoir will be connected with the sewer by an iron pipe (6 inches in diameter) furnished at one end with a stop valve and at the other with a sluice gate. The water from the filtering well will pass into the reservoir through a small pipe, and when the reservoir has sufficient water collected in it, the pipe will be closed by a self-acting ball-valve.

In order to flush the sewer, the man employed on the work will first open the trap door at the surface of the gronnd—he will then descend the ladder, and, pushing the box of charcoal into its recess *e*, pass down to the bottom of the man-hole shaft. A few turns of the handle fixed to the stop valve will open the mouth of the flushing pipe, when the water from the

reservoir will rush through it, open the sluice gate k by the force of its pressure, and pass into the sewer with considerable velocity. After all the water has escaped, the sluice gate will fall down by its own weight, and the stop valve will be closed by the man, who may then leave the reservoir to fill again, and pass up the ladder to the open air. As soon as the reservoir is emptied, the water from the filtering well will begin to flow into it, and in the course of a few hours the whole apparatus will be again ready for use.

It is expected that a pressure of 2 feet of water in the reservoir will give a sufficient scouring velocity to the water. If, however, this amount of pressure should, in practice, be found insufficient, the reservoir can be filled to the depth of 3 feet by altering the position of the ball-valve.

The Outfall Sewer and the St. Thomè Branch Sewers must be flushed by forming temporary dams across them and removing the dams suddenly. This is practised in England and found to answer.

All the sewers and other works will be constructed with machine-made steam pressed bricks laid in the best hydraulic cement. The inner surface of the sewers and other works will be lined with asphalte half-an-inch thick, and the inverts of the sewers will be formed with earthenware blocks of English manufacture. Round those sewers which run beneath the level of water, there will be a casing of concrete. A general idea of the form of the sewers and the manner in which they will be constructed, may be obtained from the accompanying diagram.

Pumping arrangements.—Assuming that 20 gallons of water will be used, per diem, per head of the population, the total quantity of sewage to be raised by the steam pumps daily would be :—

Population of Madras.		Gallons.		lbs.		
428,000	×	20	×	10	=	85,600,000 lbs.

And if half this quantity be supposed to enter the cesspool during the 8 hours of maximum flow, the power of the engines should be sufficient to raise 42,800,000 lbs. in 8 hours. The average lift from the cesspool into the outfall sewer would be $26\frac{1}{4}$ feet. The power of the pumps, therefore, should be—

$$\frac{42{,}800{,}000 \text{ lbs.} \times 26\frac{1}{4} \text{ feet}}{33{,}000 \text{ lbs.} \times 8 \text{ hours} \times 60 \text{ minutes},} = \text{say } 70 \text{ horses.}$$

I consider that two engines, each of 36 horse-power, would be ample for all purposes. I would not recommend the erection of a third engine as a

reserve, for I very much doubt if, for many years, the quantity of water used daily per head of the population, will even approximate to 20 gallons. Indeed, one engine of 36 horse-power would, in my opinion lift all the sewage that might flow into the cesspool during any hour of the day. The second engine, therefore, would be as a reserve. If, at any future period, it were found that these two engines were not sufficient for the work required of them, a third could easily be procured, but it would be very unadvisable to go to the expense of providing more engine power at first than could be utilized afterwards.

By the cesspool, to which I have alluded so often, it must not be supposed that a large reservoir for ponding up the sewage for many hours is intended. This system, which is practised in England, and of which the most notable examples are to be found in the grand London Drainage Works, is obviously not suited to a country like India where decomposition sets in so rapidly. The cesspool for the Madras Drainage Works, will be a small well of, perhaps, 8 or 10 feet in diameter, into which the sewage will be led for conveniences of pumping. During those hours of the day when there is a little or no sewage to be raised, the engines will be stopped and the sewage will be allowed to accumulate in the Main Sewer, which, in fact, will be the ponding reservoir, and take the place of those enormous cisterns which are constructed in Europe.

As so many improvements are yearly made in England in pumping engines, of which the Indian Engineer is not so much as aware, I have thought that it would be useless for me to attempt the designs for the engines for the Madras Drainage Works. Much better designs could be obtained by the Government from some one of the numerous Engineers in England, who devote their entire attention to this class of work. A few remarks as to the requirements of the engines for Madras will not be out of place here. 1st. The boilers must be constructed on the most improved principles, and with the view to the smallest consumption of fuel in proportion to the work performed. Where, as in Madras, coal is sometimes not to be had at less than 50 shillings per ton, the necessity for the careful construction of the boilers, with the object of saving fuel, cannot be exaggerated. 2ndly. The furnaces must be made for the combustion of either coal or wood. 3rdly. In connection with the pumps, arrangements must be made for separating, if necessary, the liquid from the solid portion of the sewage: and a filth-hoist for the purpose of raising the latter must

be erected to be worked by the engines. I would leave it to the Engineer in England to decide what style of engine should be adopted—whether high or low pressure, whether condensing or non-condensing, whether single acting or double acting, &c.

On receipt of the plans of the engines, the buildings at the Pumping Station can be designed. With this report is forwarded a plan and sections of the ground where the sewage is to be raised, and such information is given on the plan as will enable the Engineer in England to understand the special requirements of the case

Street Drainage.—The street drainage will be effected by means of 9-inch and 6-inch glazed earthenware pipes of English* manufacture. Only in one instance will a pipe of larger dimensions be laid down. I propose to use pipes of these two sizes as the most convenient for the objects in view. Every street will be drained by a 6-inch pipe leading to a 9-inch sub-main, which will run directly to the main or branch sewers. The 6-inch street pipes will usually begin at 3 feet below the surface of the ground, and will slope down uniformly to meet the 9-inch sub-mains. The least slope for the 6-inch pipes will be at the top of the ridges in each District (about 1 in 150), and the greatest slope in those streets which are nearest the main and branch sewers (about 1 in 50). In laying down the street drains, it will be necessary to provide means of access to them at intervals of about three hundred feet apart, so that they may be easily cleansed when obstructed. In connection with these entrances leading to the drains, ventilators and small flushing reservoirs might be formed, similar to those adopted for the sewers. Where the pipes were above the level of the water, some other means of flushing would have to be arranged. A water-cart, with a long hose, would, perhaps, be the simplest plan.

I would strongly urge that the pipes used for the Madras drainage be of the kind known as "saddle and chair" pipes. If they get broken, they can easily be removed, and others can be substituted without shifting more pipes from their position in the line than the number to be replaced.

House Drainage.—The house-drainage will be effected by three and four-inch earthenware pipes laid at as great an inclination in each instance as the internal arrangements of the walls and rooms of the dwelling will admit of. The pipes will start from the back yard of the house and will issue into the street from under the front door of the dwelling. The admirable system

* Why should not these be made in India?—[ED.]

known as "back drainage" in England cannot be adopted in Madras. The destruction of property would be so great as to put it entirely out of the question. In London, where there is generally an open yard at the back of every house, there is no difficulty in draining the houses to the rear—in fact, it is cheaper to do so, but in Madras the back-yard to the house is surrounded by small buildings, the destruction of which would be necessary before a pipe could be laid. Every house, moreover, invariably slopes, and some very considerably, *from* the back yard *towards* the street. To attempt "back drainage" will be to drain the houses against the natural slope of the ground. Many objections may be found and urged against carrying the pipe through the entire length of each man's dwelling and taking it into the street drain from under his front door, but long attention to this subject, and a careful inspection of numerous dwellings all over the town, have convinced me that this is the only method at our disposal. It is not possible to make use of the present house drains, which are usually channels of about 4 inches square, and run beneath the wall which separates two contiguous buildings, and is common to both. These drains having been built along with the houses, there is no means of getting at them except by pulling down the walls, which cannot be done without causing damage to the dwellings. In many of the streets, the slopes which have been given to these channels are very slight, and they constantly become choked up in consequence.

I would, therefore, leave the present house drains as the discharging channels for rain-water, and would lay down three and four-inch earthenware pipes in the manner already proposed for the sewage. In every yard, or wherever water may be used within a native dwelling, there would be a small cistern fitted up with a sink. The earthenware pipe, which would run from the back to the front of the house, would, in most cases, pass directly under these sinks and be connected with them by syphon traps.

To illustrate my meaning, I will take the most ordinary case—a native dwelling with, say, three open yards, one behind the other, and with a well in the back, and another in the front, yard. The earthenware pipe would start from near the well in the back yard, run across the second yard to the well in the first yard, and thence pass through the dwelling and out under the front door. It would join the street drain in the middle of the street. Round each well it would be necessary to put up a brick dam two or three inches high—just sufficiently high to intercept the

water, and sufficiently far from the parapet of the well to admit of the inmates of the dwelling bathing and cleaning their pots in the space between the parapet and the dam. A sink would be fixed in this open space so that all the water that was used at the well would escape through the sink and pass at once into the earthenware pipe. In many cases the dam would not be required, for there is already a channel from each well, and the sink might at once be fixed in it. Care should be taken not to lay it at the lowest point in the open yard, as in that case, the rain falling on the roofs of the houses and in the yard would enter the earthenware pipe.

The house drainage should be carried out under the immediate direction of the Municipal Commissioners. Every house-owner should be at liberty to lay down the drains in his house himself, subject to the approval of the work by the Commissioners, or, if he preferred it, the Commissioners should lay down the drains for him at their own cost, and increase the rate charged on the house by such a sum as in 30 years would amount to the value of the work done, with interest thereon.

I must not omit to explain in this place how I intend that the excreta should be disposed of. So far as the urine is concerned the matter will be very simple. The connection at present between the privy drain and the house drain will be stopped, and the former will be joined to the new earthenware pipe through which all the urine will escape to the sewers. For the removal of the ordure I would encourage, as much as possible, the system which obtains at present throughout the town,* but I would, at the same time, try to improve it. The abominable smells in all parts of Madras are not produced, as is generally supposed, by the excreta of the population, but by defective drainage. It is the *refuse water* in the houses and in the streets into which all manner of garbage is thrown to ferment, and generate foul gases, that creates the dreadful nuisances so much complained of. What is chiefly required to prevent excreta producing a nuisance is a constant inspection of the privies in the dwellings. Although the ordure is removed daily, yet the privies themselves are not kept clean. Very often there is a stoppage in the channel which carries away the urine, or the ordure is dropped on the bare floor from which it is impossible to remove it altogether. Now, if the Municipal Commissioners would organize a system of inspection and insist on every householder keeping

* *Vide* page 3 .

his privy in a wholesome state, we might soon get rid of the evil. Of course, the use of clay, ashes, &c., should be encouraged as much as possible. This would be nothing more than the dry system applied to dwellings, and would have this advantage, that each householder would be saddled with no more than the expense of removing the nuisance produced in his own house and by his own family. The cost of this plan to the Municipality would really be most trifling. For the first few months it might be necessary to examine each privy once in every two or three days, but after a few men had been punished for the filthy state of their privies, even this amount of inspection would not be called for. A weekly inspection would subsequently answer every purpose. Twenty-five Native Inspectors would suffice for the whole of Madras. In each District there should be one European or East Indian Superintendent, who should keep the Inspectors up to their work, and receive their daily reports. Both the Superintendent and the Inspectors should have no work but that of looking after the privies.

If each Superintendent received 30 rupees, and each Inspector 7 rupees, monthly, the total yearly cost of (say) eight Superintendents and twenty-five Inspectors would not amount to 5,000 rupees. The only objection which may be urged against this scheme, is, perhaps, that the householders would object to the privacy of their dwellings being invaded for the inspection of their privies. But, considering that ultimately the privies would not require to be inspected more than perhaps once a week or so, and that sweepers at present enter each house every day to clear away the ordure, the above objection would really be an absurd one.

The best system for the removal of excreta is the sewer system—provided that plenty of water can be employed to carry away the urine and ordure, and that a liberal use can be made of some deodorizing solution to prevent effluvia. There is nothing to equal the water-closet for cleanliness and wholesomeness. It acts perfectly if deodorizers are used as well as water. Both deodorizing and antiseptic solutions will, before long, be procurable at prices that will admit of their free use even by householders, but many years must elapse before every house in Madras is supplied with water. Until then, I am satisfied that it will be best to continue the present system.

Utilization of Sewage.—Having now explained the Project generally, it is necessary that I should return to a point in connection with it, to which

I have hitherto only alluded, in order that the description of the works should be as clear and uninterrupted as possible. Under the heading "Objections to Sewers," I have already attempted to prove that sewage is a valuable manure, and that those who are best qualified to speak on the subject are unanimous in their opinion, that it should not be wasted but applied to agricultural purposes. It is unnecessary, therefore, that I should repeat the arguments in this place. The points to which I now wish to draw attention are the very favorable position of Madras for the utilization of its sewage, and the rare opportunity thus afforded to Government of making an experiment on a large scale on this very important question of the day.

The land on which it is proposed to use the sewage, lies to the north-west of Madras. It is a portion of that extensive low-lying tract stretching toward the north, along which the canal runs. The average level of the land is from 2 to 6 feet above datum (mean sea level). It is not possible to say how much land will be required; that will depend on the quantity of sewage available. But if this quantity should be even ten times as much I have allowed for, there is more than sufficient land for the purpose. The only objection which I can conceive will be made to the use of the sewage, is the general one that a nuisance will be created in Madras whenever the wind blows over the sewage-irrigated land towards the town. This objection I shall, therefore, at once attempt to meet.

The accompanying Chart shows the number of days in the year the wind blows in Madras from each point of the compass. All those winds marked with arrows are winds which would convey the smell of the sewage away from Madras. The other winds would blow over the sewage lands to some one or other inhabited quarter of the town. Now, a glance will convince any one by how very much the favorable winds exceed the unfavorable ones. While the latter blow for less than three months, the former blow for more than nine months of the year. It must not be supposed that each wind blows *continuously* during the number of days marked in the Chart. What is meant to be shown is, that the total number of days in the year during which the wind blows from any one point of the compass amounts to that shown in the Chart. The winds N. E. by N. and N. N. E., which I have marked as unfavorable, are really in only a very slight degree so, for they would have to travel nearly two

miles before they reached the nearest inhabited part of Madras, which would be the outskirts of Pursewakum. The nuisance, if there were any, which I altogether doubt, would, at all events, be so very slight as to be scarcely felt.

On the accompanying Map of Madras I have shown the position of the sewage-irrigated lands, and have projected the directions of the winds so that the course taken by each may be at once seen. The only winds, if any, which would be positively unfavorable, are those which blow from between W. by N. to N. by E., but, practically speaking, there are no winds from between W. to N. Only occasionally, for a day or two in each month of the year, does the wind blow from the points between these quarters. It never continues in them. To render this clear I have drawn the accompanying diagram which shows the number of days in every *month* of the years 1847, 1848, 1849 and 1850,* during which the wind blew in Madras from each point of the compass. It will be noticed how thinly scattered over all the months of the year are the days on which the wind blew from between N. and W.

I think it will now be admitted that no inconvenience will be likely to arise from the use of the sewage on the site I have pointed out. But should the Government have any doubt on the matter, it would be very easy to select a much better site by going further away from Madras. It is a question of expense only, for the farther the land is situated, the longer must be the channel which conveys the sewage to it. I have merely chosen the nearest site on which I consider sewage might be applied without objection being made. My opinion is that the sewage might even be used around the very spot on which it is pumped up from the cesspool, without any nuisance to the inhabitants.

I had partly designed an Irrigation Sewer, but I subsequently decided not to complete it, as it was essential to know first what site the Government might select for the utilization of the sewage. The great advantage of using the sewage will be the saving effected by not having to construct the Outfall Sewer, a work that will cost about three lakhs of rupees. Besides this, the sale of the sewage may be expected to realize a considerable sum.

I beg respectfully to urge on the attention of Government the great im-

* I have not *selected* these years, but the Government Astronomer (N. R. Pogson, Esq.), gave me the records of them as being those which were in the most convenient form for reference. No records of later years have as yet been published.

portance of this question of utilizing the sewage of Madras. Every town in India has an interest in its decision, and could it be proved that the sewage of towns could be profitably and safely applied to land in India, an incalculable benefit would be conferred on the whole country.

Cost of project.—The following is a list of the quantities of work to be done, and the rates at which they are calculated :—

Quantities.	Description of work and rate.	Amount.
	MAIN DRAINAGE.	
Cub. ft.		Rupees.
1,337,751	Brickwork in hydraulic cement, Rs. 0-6 per cubic foot,	5,01,657
1,718,121	Concrete, at Rs. 0-2 per cubic foot, ...	2,14,765
Sq. ft.		
1,053,100	Asphalting, at Rs. 15 per square of 100 feet, . .	1,57,965
7,000	Plastering, at Rs. 2-8 per square of 100 feet, . .	175
Run. ft.		
104,928	Invert lock, at Rs. 1-8 per running foot, . . .	1,57,392
Cub. ft.		
27,106	Ashlar granite, at Rs. 1-8 per cubic foot, . . .	40,659
Cub. yds.		
529,169	Earthwork, including excavation, re-filling, re-making road and every expense, at Rs. 1-4 per cubic yard, ...	6,61,461
991	Tunnelling, at Rs. 7 per cubic yard, . . .	6,937
33,281	Embankment, at Rs. 1 per cubic yard, . . .	33,281
20	Gravel, at Rs. 1-2 per cubic yard, ...	23
Cub. ft.		
809	Teakwood, at Rs. 3-4 per cubic foot, . . .	2,629
Sq. ft.		
4,203	Galvanized iron netting, at Rs. 0-6 per square foot, .	1,576
℔s.		
31,614	Wrought-iron, at 150 rupees per ton, . . .	2,117
Number.		
1,104	Rivets, at Rs. 0-1-6 each, ...	104
336	Cast-iron ventilators, at Rs. 30 each, ...	10,080
336	Trap doors, at Rs. 140 each, ...	47,040
263	Ball valves, sluice valves, sluice gates with pipes complete for each flushing reservoir, at Rs. 90,	23,670
Tons.		
6,258	Granite boulders at Rs. 2 per ton, ...	12,516
	Total Rupees, .	18,74,047
	STREET DRAINAGE.	
Run. ft.		
577,490	Six-inch glazed earthenware pipe drains, including digging, laying down, jointing, filling up, and every expense, at Rs. 1-4 per running foot,	7,21,863
61,400	Nine-inch do. do. do. at Rs. 1-12 per running foot, ...	1,07,450
2,800	Twelve-inch do. do. do. at Rs. 2-4 per running foot, ...	6,300
Number.		
214	Man-holes and side-entrances for the nine and twelve-inch pipes, at Rs. 500 each, . . .	1,07,000
	Total Rupees,	9,42,613

I have thought it best to show clearly the exact quantities of work and the rates at which they are calculated, so that an opinion may be formed by the Government on the Estimate.

For sewerage works none but the best procurable materials should be used. Admirable steam-pressed bricks have already been made in Madras—sufficiently good for any engineering purpose. I propose to use bricks similar to these for the Madras sewers. Hydraulic cement can be made wherever lime and clay are to be had, and I have no doubt excellent cement will be produced when the time comes to begin the works. In London, brickwork for sewers, when the bricks are picked stocks and laid in Portland cement, costs under a shilling a cubic foot; but such brickwork will not be attainable in Madras. Brickwork with picked stocks in blue lias lime costs under 9*d.* a cubic foot. I have taken 9*d.* or 6 annas, as the rate for the Madras sewers.

In London, concrete, composed of blue lias lime and clean ballast, costs under 3*d.* per cubic foot. I have taken 3*d.* or 2 annas, as the rate for Madras. Hitherto, I believe, concrete has cost somewhat more than this; but it has been made in such small quantites, that it is difficult to say what the cost will be when it is manufactured on a large scale.

I think it will be necessary to coat the interior surface of the sewers with asphalte, and I do not apprehend any difficulty in the work, as the brickwork will all be built in blocks on the surface of the ground before it is laid in the sewers. The cost of the asphalte coating will, I think, be covered by the rate allowed for it, viz., 15 rupees per square of 100 feet.

It is most essential that the inverts of the sewers should be laid with the best material. They are exposed to much more friction than the other parts of the sewers. For smoothness of surface and for durability there is nothing to equal the glazed earthenware blocks which are now manufactured and used in such large quantities in England for the inverts of sewers. They have been laid down in the London sewers at 2*s.* per running foot. I have allowed 3*s.* or Rs. 1-8 per running foot for Madras.

Earthwork, including digging, re-filling, tamping, shoring, pumping, keeping the works clear of water, re-making road-ways, and every expense whatsoever, has been done for the London sewers at 2*s.* 6*d.* per cubic yard. There is no reason why this rate should be exceeded in Madras.

Six-inch glazed earthenware drain pipes have been laid down in London at 2*s.* per running foot, including digging, re-filling, and every expense

whatsoever. Nine-inch pipes have been laid at 2*s.* 6*d.*, and twelve-inch pipes at 3*s.* per foot run. The rates I have adopted for the Madras sewerage are,—for the six-inch pipes, including all bends and junctions, Rs. 1-4; for the nine-inch, Rs. 1-12; and for the twelve-inch, Rs. 2-4 per running foot. The use of none but the best earthenware pipes should be contemplated. It would be folly to use country-made pipes as they are manufactured by the potters at present.*

I have assumed that each Man-Hole or Side-Entrance for the street drains will cost 500 rupees. The quantities of materials will differ according to the position of each, but I think the above will be found a near approximation to the cost.

The other items in the preceding estimate are of small amount, and it is not necessary that I should refer to them, as any slight alteration in the rates for them will affect the total cost of the works in only a slight degree.

Some land will have to be bought up for the works, and the value of this has been ascertained, in communication with the Collector's Department, at 25,340 rupees. A few small buildings in the line of the sewers will likewise have to be purchased. The cost of these will be 20,000 rupees. The cost of the engine and pumps (72 horse-power) has been calculated at 1,500 rupees per horse-power, delivered in Madras, or altogether to 1,08,000 rupees. The Pumping Station, and works in connection with it, (including expenses of erecting the machinery) will, it is calculated, cost 70,000 rupees. There are no plans for this work, as I have already explained, but I believe 70,000 rupees will cover all expenses.

The total estimate for all the works is as follows:—

	Rs.
Main drainage, ...	18,74,047
Street drainage, ...	9,42,613
Land to be purchased, ...	25,340
Buildings do., ...	20,000
Engines and pumps of 72 horse-power, at 1,500 rupees per horse-power, ...	1,08,000
Pumping station, including cost of putting up machinery, and other works, ...	70,000
Total Rupees, ..	30,40,000
Add about 10 per cent. for sundries and contingencies, ...	3,10,000
Total Rupees, ..	33,50,000

* But there is no reason why they should not be improved. Witness the earthenware pipes now made at Allygurh by the Irrigation Department, N. W. P. *See* No. CXVI. of these Papers.—[ED.]

If Government decide, as I trust they will, that the sewage shall be utilized for agricultural purposes in the neighbourhood of the Pumping Station, the cost of the Outfall Sewer, about three lakhs of rupees, will be saved. An Irrigation Sewer will, in this case, have to be built, but its length need not be more than one-third that of the Outfall Sewer, and its dimensions need not be so great. The cost of the Irrigation Sewer may be put at about a lakh of rupees. Deducting the cost of the Outfall Sewer (about 3 lakhs of rupees) from the amount of the above estimate (33½ lakhs) and adding the cost of the Irrigation Sewer (say a lakh of rupees), the total of the estimate becomes 31½ lakhs.

It will be seen that I have allowed the large margin of upwards of 3 lakhs (10 per cent. on the estimate) for unforeseen contingencies.

The cost of the establishment for superintendence will probably be as follows:—

		Rs.
1	Mechanical Engineer, specially brought out from England to superintendent the working of the engine and to keep the accounts, ...	400
2	European or East Indian engine-drivers, at Rs. 50 each,	100
4	trained firemen, at Rs. 15 each, ...	60
4	ordinary firemen, at Rs. 8 each, ...	32
25	men (mostly sweepers) to look after the sewers and pipe drains, and to be available generally for any work, at Rs. 5 each, ...	125
1	Storekeeper and accountant, ...	50
1	Clerk, ...	25
4	Peons, at Rs. 6 each,..	24
	Monthly cost, Rupees, ..	816
		12
	Yearly cost, Rupees, ..	9,792

If 5 rupees yearly represent a Capital of 100 rupees, the above sum for superintendence would represent a capital of (9,792 × 20 =) say, 2 lakhs of rupees.

I think it may fairly be assumed that for many years to come, the quantity of sewage will not exceed 10 gallons per diem per head of the population. The total quantity of sewage to be raised by the pumps daily, taking the population of Madras at 430,000, would, therefore, be 4,300,000 gallons. Good engines of the largest size (of about 200 or 300 horse-power) lift from 2 or 3 million gallons of water a hundred feet high with a ton of coal.

Small engines (such as those proposed for the Madras Drainage) would not lift more than half this quantity, or say 1¼ million gallons a hundred feet high. This is equivalent to more than 4½ million gallons 27 feet high, which is the height to which the pumps will have to raise the sewage. About a ton of coal or say 1½ tons at the outside, will, therefore, be consumed daily in Madras. The cost of coal, if imported direct from England and not purchased in the local market, may be taken at 20 rupees a ton. The yearly cost for fuel will be (365 × 30 =) 10,950 rupees.

To this sum we should add, say 2,050 rupees for oil, tallow, and other sundries, which would then make the total yearly expenditure about 13,000 rupees. This would represent a capital of (13,000 × 20 =) say 2¾ lakhs of rupees.

If the works are properly executed in the first instance, and a sufficient establishment, such as that proposed, is maintained to look after them, the repairs ought to cost little or nothing. There are sewers at home which have cost nothing for repairs for years after they have been laid down. But I will assume that the repairs every year will amount to ½ per cent. on the cost of the works, *i. e.*, on 31½ lakhs, supposing that the Outfall Sewer is not built. This will be equivalent to, say, 16,000 rupees yearly, or to a capital of about 3¼ lakhs.

The total estimate, then, under all heads, will be as follows:—

Cost of works, ...	31½ lakhs.
Superintendence, ...	2 „
Fuel and sundries, ...	2¾ „
Repairs, ...	3¼ „
	39½ lakhs.

We are now in a position to compare the cost of sewerage with that of Dry Conservancy. In my estimate above of 39½ lakhs of rupees, I have included every possible charge. I will even assume now that the works may cost as much as 50 lakhs, or half a million pounds sterling. And what will the rate-payers receive for this sum? All liquid refuse will be removed from the precincts of their dwelling and will be utilized on land. Ultimately, I have no doubt that the value of the sewage for agricultural purposes will repay the cost of maintenance, but I will not assume this now.

The Estimate I prepared of the cost of Dry Conservancy* was 75 lakhs

of rupees. But I did not include the cost of procuring clay, which amounted to 31 lakhs, and I excluded all cost of repairs and a number of other items. The calculations based on the enquiries made into the cost of Dry Conservancy by the Sanitary Commissioners, brought up the cost of this system to 258 lakhs. Let me suppose, though for argument's sake, that a million pounds sterling will cover all expenses. We then have half a million pounds sterling for a system of sewerage by which all liquid refuse is removed, and a million pounds sterling for Dry Conservancy by which only urine and ordure are removed, which together amount to *one hundredth* part of the sewage. So that it will cost at least twice as much to remove urine and ordure only, according to the Dry Conservancy system, as it will to remove a hundred times their amount of sewage by the Sewer system.

It has been urged that the cost of draining Madras according to this Project will amount to as much as the value of all the house property in it, and that it will be better to remove the town bodily, as the Americans remove their houses, than to attempt to drain it. It is best to meet arguments of this kind by facts. The value of a house is usually considered equal to 30 years' rental. The number and yearly rent of all the houses in the town may be obtained by any one from the Municipal Commissioner's Office, and the value of all the houses will be found to be 850 lakhs of rupees, or $8\frac{1}{2}$ million pounds sterling. Half a million pounds sterling (the assumed cost of this Project) is not 6 per cent. on the value of the houses at present, and a good system of water supply and drainage will raise their value in the course of a few years by at least twenty per cent. Money laid out in water supply and drainage works is merely capital sunk to improve house property. The inhabitants recover the outlay by the enhanced value of their houses.

There is an impression that Madras can be drained for a very small sum of money. I have no hesitation in saying that the idea is absurd. It is possible to have a cheap system of water supply, but it is utterly impossible to have a cheap system of town drainage. In supplying a town with water, you may carry a few pipes to a few central stations and make the inhabitants fetch their water from them. But in draining a town, you must carry a pipe from *every single house* in the town, without exception, to some one central spot. The length of drains in the latter instance becomes enormous. Whatever scheme of drainage is adopted for a town,

the length of the sewers and pipes must be almost exactly the same. In the case of Madras, there must be about 140 miles of sewers and pipes, or, if not, some parts of the town will be left undrained. For whatever sum of money 140 miles of drains can be laid down, for that sum only, and for no less, can Madras be drained.

It is necessary for me to add only, that the success of this, or of any Project for the drainage of the town, will depend, in a great measure, upon the manner in which the works are executed. Contractors who have had practical experience in sewerage works will have no more than the ordinary difficulties to contend with in the building of the sewers and the laying down of the pipes for Madras, but should any one attempt the work who is unacquainted with town drainage, certain failure will overtake him. In the present day, contractors in England have attained great skill in the execution of sewerage works, and I therefore, venture to recommend that, when the Government shall have come to a decision on the subject, they should invite tenders for the Madras Drainage Works in London and accept not necessarily the lowest tender, but the tender of some well-known builder who has already proved himself competent, and who possesses the requisite amount of capital for the undertaking.

H. T.

No. CXL.

WEDGE BRICKS FOR ARCHES.

Memo. on the designing of Bridges and Culverts; drawn up for use in the 3rd Circle, P. W. Department, N. W. Provinces. By MAJOR J. G. R. FORLONG, C.E., F.R.S.E., *Superintending Engineer.*

THE accompanying table has been framed as a general guide in designing Bridges and Culverts of certain dimensions, and with the object of collecting data as to the cost of such, as estimated and as built.

It is necessary to explain the system seen here of using wedge bricks, which the writer has employed in bridges, culverts, relieving arches of doors in buildings, &c., &c., ever since their invention (if it can be called such, by Captain Best of the Madras Engineers) in 1847.

This one form of wedge [*Fig.* 1] can be used in *any* arch and with *any* kind of rectangular brick, and is a complete preventive of bad work, such as mortar dodging towards the extrados, in order to get the curves, the common artifice of all builders.

The wedge course occurs at true calculated distances, and a simple inspection of the face, or of the extrados or intrados of the arch, will at once prove if it is true and good work and according to specification; and this no other system will do, not even if all the bricks were true moulded voussoirs, for amidst such a mass of wedges, an ever increasing or decreasing error will be found in large arches, which will in practice throw out the true calculation of the number of voussoirs. In this system the wedges are so few as not to affect such, even in the largest arches.

A half section of an elliptical arch of 36 feet span, built about 17 years ago

by the writer, accompanies this, to show the occurrence of the wedges in curves of different radii in the same arch.

The wedges here used were $9 \times \frac{4\frac{1}{2}}{2\frac{1}{4}} \times 2\frac{1}{4}$ inches, with rectangular bricks $9 \times 4\frac{1}{2} \times 2\frac{1}{4}$ inches, and such are the best sizes for all arch bricks; common walling bricks in India are usually $12 \times 6 \times 3$ inches, which is a little too long for the wedge. If so long, it is apt to be broken in transit.

If the wedge is not the same length as its rectangular brother, the result will be as shown in *Fig.* 2, according to the thickness of voussoir.

The rule for finding the wedge courses is seen in the case of 9-inch bricks at foot of table; it is generally $\frac{R'' \text{ radius}}{\text{length of brick}}$. The quotient is the number of courses *between* each wedge brick, counting from the crown which is itself a wedge.

Example.—Radius of an arc of 24 feet rising $\frac{S}{4} = 15$ feet, which $\times$ 12 $= 180$ inches; $\frac{180}{9} = 20$, which is the number of courses the wedge bricks will be apart, to form this curve. As a course is here $2\frac{1}{4}$ inches, this $\times$ 20 $=$ 45 inches length on intrados between wedges, and as* intrados $= 333\frac{1}{3}$ inches, half of this on each side of crown $= 166\frac{1}{3}$ inches, which divided by 45 $=$ 3 wedge courses and $31\frac{2}{3}$ inches. This, however, mistries to assure themselves of no mistakes, ascertain practically by laying down the curve with radius and bricks, all full size, on the ground, remembering to allow for the mortar.

The number of wedges required in each wedge course for an arch of which the roadway (R) $=$ 18 feet; will $= 18 \times 12$ inches $=$ 216 inches, length of arch in inches, which divided by $2\frac{1}{4}$ inches $=$ 96 wedge bricks in each line of wedges. This multiplied by the 7 courses for 9 inches depth of voussoir, gives 672, and for 18 inches gives 1,344 wedge bricks.

It is as easy to make bricks of one size as another, the contractors being merely supplied with the different kind of moulds. These should have rims of hoop iron, and be large enough to admit of the shrinking of the clay.

This opportunity may be taken of stating that in large arches, it is a good plan to use 1 ℔. of goor† water (or tolerably strong glutinous water,

* $\frac{(\text{Chord of } \frac{1}{2} \text{ segment} \times 8) - \text{chord of whole segment}}{3}$ = arc of whole segment. In this case $\frac{(13' \cdot 5'' \times 8) - 24 \text{ feet}}{3}$.

† Sugar.

made by boiling down bullock or dog skin) to every 2 cubic feet of unslacked lime, and the same in plaster, with the addition of the hair of the animal; for the latter, the mortar should be made up, and stand for 15 days, and for the former, it is best made up as required.

Instead of painting or plastering bridges and culverts, the following has been found a far cheaper, and generally as good, a preservative. Rub the whole surface of walls, soffits, &c., with a deep red, but softish brick, dipped in fresh lime (not mortar) and strong goor water, of 1℔. to the gallon to 1 ℔. of fresh lime. The rubbing to continue till the surface is quite smooth, and the whole nearly set. The cost of this has been ascertained on a large bridge near Agra not to exceed 8 annas per 100 square feet, and should always be done before removal of scaffolding. The freshly ground soorkhee rapidly and firmly sets, and care should be taken not to rub after it begins to set, but to have the whole surface then level.

AGRA,
April, 1867.

J. G. R. F.

Class.	P. width of Pier. P.	F. Foundation allowed for below level of bed.	W. Water-way, square feet.	R. Road-way, including parapets.	Remarks.	H.	Actual and estimated cost; the latter in black figures. Estimate.	At per Square foot of W. W. water-way.	At per Lineal foot of span
							RS.	RS.	RS.
Barrel culverts, 4th class, being cylinders, 24 to 36 feet long, ...	None. Cylinders merely laid along side each other	1·6	3	21 ft, which may be increased 2·6	Minimum height for cylinders of these lengths and diameters.	16 0	{ 100	24	36
		2 2	7	4·0		6·0	{ 110		
		2 2	12½	4·6		7·0			
		2·2	19½	5·6		8 0			
	1 1½	2·0	39	24 feet.	As actually built in 1855-66.	9 0			
Arched only, 3rd class, .	..	2·0	20			6·0			
	1 6	2·0	49			9·0			
	1·6	2·6	54			9 0			
,, 2nd class, .	1·6	2·6	108			9·0			
,, 1st class, .	2 0	3·0	105			12·0			
Bridges, 4th class, .. .	2 6	3·6	169	18 feet		15 0			
	3·0	4 0	202½			18·0			
	3 6	4 6	288¾			21·0			
,, 3rd class, .. .	4·0	5·0	378			21·0			
,, 2nd class, .. .	4·0	5·6	492¾			24·0			
	4·6	6·0	532½			24 0			
	5·6	7·0	621			24 0			
	6·0	8·0	245			30 0			
,, 1st class, .. .	6·0	8 6	990			30·0			
	6 0	9·0	1,008			30 0			
	6·0	10·0	1,037½			30 0			
,, ,, .. .	$\frac{S}{8}$	Of course this depends on the site. These depths are merely assumed for estimate purposes.	S × height of abutment $+ \left(\frac{VS}{2}\right)$						

Note 1st.—To find rrer *top of*
Diameter = VS + $\frac{}{4}$ ge 1·6″ be-

5*th*.—The bricks are assumed to be 9″ × 4½″ × 2¼″
and the wedges 9″ × 2¼″ × { Top width, 4½″; Bottom, 2¼.

J. G. R. F.

No. CXLI.

IRRIGATION IN MYSORE.

Abridged from a Report by MAJOR R. H. SANKEY, R.E., *Chief Engineer, Mysore.*

I HAVE the honor to reply to Circular No. 25, of the Government of India, dated 22nd March, 1866, calling for information regarding irrigation projects which, while proving remunerative to the State, should be primarily "calculated to prevent the occurrence or mitigate the severity of drought and famine," and requesting that a "review be made of the projects completed and in progress."

While most desirous of confining my remarks strictly to the points adverted to by Government, the nature of the subject in its bearings on this part of the country, necessitates more general treatment than would elsewhere be requisite. This is owing simply to the vast number of irrigation works, which the physical condition of Mysore, in common with much of the rest of Southern India, has given rise to in past ages.

Excepting in the Mulnád or rainy tracts of the Western Ghauts, it is almost needless to say that the first necessity of a fixed society, next to that of providing itself with shelter, must have been the construction of reservoirs for arresting and storing up the rain-fall which, from the peculiar conformation of the ground, and nature of the soil, would otherwise have escaped to the sea, or been lost in other ways.

The storage of water for irrigation, doubtless followed closely on its collection simply for domestic purposes. In all the open country we therefore now find, that population has little or no existence, excepting in con-

nection with works of this description. And hence, to deal with the immediate and pressing wants of a people so situated, attention must of necessity be primarily devoted to the repair, development or reconstruction of existing tanks and channels. As regards entirely new projects, their superior attractiveness to the Engineer will sufficiently ensure their not being forgotten.

It will be sufficiently obvious from these brief remarks that the subject as proposed by Government, has here a widely different signification to what it necessarily would have in Northern India, where, from the presence of other physical characteristics, irrigation is for the most part a late introduction, and modern Engineers have had, so to speak a "tabula rasa," whereon to sketch their projects.

A general view of the existing irrigation works of Mysore, however imperfect, consequently appears to me inseparable from any proper consideration of the matter in hand. But before proceeding to deal specifically, with the two heads into which the subject naturally divides itself, (viz. (I.) Tanks, (II.) Anicuts and Channels), I would invite attention to the accompanying Map, showing the distribution of the two systems of works, with the general conditions under which they have grown up and are at present found to exist.

The unshaded portion of the map is the actual surface of the country, the drainage of which is caught up and stored in tanks. The shaded portions are those whose drainage, on the other hand, though partially used for rice and garden cultivation in the rainy and forest tracts, and partially diverted by anicuts in the lower reaches of the several streams, escapes nevertheless for the most part unutilized beyond the limits of Mysore and Coorg, and eventually, in great measure, to the sea.

The thin colored lines are the watersheds of the several streams, laid down carefully, like the above, from the Indian Atlas; those of similar tint belonging to the same main river systems. It will be thus seen, that Mysore gives birth to all the great rivers of the Southern portion of the Peninsula, and has therefore a primary natural right to the use of their waters, a position, which it will be shown further on, her people have not neglected.

To elucidate this portion of the subject I have drawn up the annexed Table.

MYSORE & COORG

RIVER SYSTEM.

Scale, 10 Miles to one inch

The blue figures show the annual Rainfall in inches

Areas given in Square Miles

MYSORE RIVER SYSTEMS.	Total length of the main rivers with their principal affluents within the Province.	Area over which the drainage is unintercepted by Tanks in Mysore.	Area over which the drainage is intercepted by Tanks.	Total area of each catchment basin.	Percentage of whole area under the Tank System.
	Miles.	Square Miles.	Square Miles.	Square Miles.	
I. Kistna river.....	611	4,814	6,217	11,031	56·47
II. Palar.............	47	...	1,036	1,036	100·00
III. Pennair..........	167	334	1,946	2,280	85·35
IV. Pennaur..........	32	222	1,319	1,541	85·60
V. Cauvery..........	646	5,526	5,769	11,295	51·75
VI. Western coast rivers.........	103	1,881	...	1,881	...
Totals for Mysore and Coorg	1,606	12,777	16,287	29,064	56·16
Deduct Coorg......	...	1,795	...	1,795	...
Remaining for Mysore..........	1,516	10,982	16,287	27,269	59·73

Were the revenue survey complete, it would be an easy matter from this to give the precise area of wet cultivation under each stream, the work done, and rent paid for their waters; but with the present inexact returns, it is useless to do so.

It will be observed that of the 27,269 square miles covered by Mysore, nearly 60 per cent. has, by the patient industry of its inhabitants, been brought under the Tank system. Unless under exceptional circumstances, none of the drainage of these 16,287 square miles is allowed to escape, or rather *should*, with proper attention, be allowed to escape, were all existing works in their normal condition. To such an extent has the principle of storage been followed, that it would now require some ingenuity to discover a site within this great area suitable for a new tank. While restorations are of course feasible, any absolutely new work of this description would, within this area, be almost certainly found to cut off the supply of another lower down the same basin—to interfere in fact with vested interests.

The activity of the nation has, by no means however, been confined to this extent of work, vast as it is. In addition to the river works, which will hereafter be alluded to, there are an enormous number of small tanks, scattered throughout the rainy tracts of Mysore and Coorg, to a great extent buried in forest glens.

The rice lands here are narrow, low lying strips placed between the spurs of the hills, retentive of moisture, and only require a tank or dam large enough to supply water, if necessary, three or four times at the most critical period of the season. These reservoirs are too small to preserve water through the dry season, and are made without sluices or stone facings; so that the water below the *codi* [waste weir] level is let out by cutting the bund. This system also applies to "tota," or garden land.

In two points these small tanks, common alike to the Nuggur Mulnád, Coorg, &c., differ essentially from those which I have classed under the Tank System. *First*, they are all individually small, placed at the head of each minor valley, and meant only for occasional use. *Secondly*, they do not exist in chains, and are consequently not mutually dependent for safety one upon the other. Being in their nature very little open to improvement, they do not affect the immediate question raised by Government, and consequently do not call for further notice.

Physical aspect of the country.—It is almost unnecessary to remark, that of the various physical causes which, while rendering possible, have at the same time fixed the limit of the Tank system, "cæteris paribus" the actual quantity of rain-fall is by far the most important, and as this again depends mostly on elevation above sea-level, it may be noted that while points on the same latitude, along the Northern and Southern frontiers, have an elevation of about 2,000 feet above the sea, there is a general rise of from 1,000 to 1,500 to the central watershed line dividing the Northern and Southern river systems. This line in fact fairly divides the country into two nearly equal areas. Though fewer heights along the Western Ghauts have been fixed than could be wished, it may be assumed that their general elevation ranges from 4,500 to 6,000 above sea-level, or from 2,000 to 3,000 above the Mysore plateau.

Judging from the actual state of things it would appear that 60 inches of rain per annum has limited the tank system; while with from 30 to 35 inches, every drop that has fallen in the country has been successfully stored. If this latter amount of rain could be counted on, there would be

little cause to fear even a scarcity of food, much less a famine, but this is unfortunately not the case in exceptionally dry years, and is more particularly observable in an almost rainless tract which I shall now advert to.

Over a large sector extending from Cuddoor through Hossdroog, the Mauri Cunawai, Heerioor, Dodary, and Mulkalmooroo, with a great extent of country on either side, the rain-fall ranges only from 10 to 20 inches per annum. And that this is due to the action of the towering mass of the Bababoodin Hills [Culhutty Peak, 6,000 feet; Moolanghery, 6,350 feet] which stands across the path of the vapour bearing S. W. Monsoon, I have endeavored in a previous report to show.*

Whatever the reason, however, the country is, comparatively to the rest of Mysore, rainless, at times almost absolutely so. Ravaged by no less than eleven Mahratta invasions, between 1760 and 1792, the unfortunate inhabitants, have also, from this physical peculiarity, periodically been subjected to the still more dreadful horrors of famine.

What the people of this District suffered since the early part of the present year, it would be difficult to say. Early in March the tanks began to run dry, and towards the end of April, they were almost completely so, not to be replenished till late in September or early last month. At the best of times in this period, there was little else than liquid mud to be procured for domestic purposes. Cholera broke out again and again, cutting off all communication between each wretched village and its neighbours. There being neither fodder nor water, the cattle, upon which the ploughing for the following years depended, died in vast numbers; and spite of every exertion on the part of the civil officers, and particularly Lieut. Pole of this Department, in giving out tank and other work, it is much to be feared that disease and famine have swept away a large proportion of the inhabitants. As it is here chiefly, that the humane intentions of Government may above all find fitting scope, several works of irrigation will, it is hoped, find place in the forthcoming Budget. These will be specially alluded to further on.

To the above imperfect sketch of the chief physical characterstics, which have either favored or limited the tank system, I would add one or two brief remarks on others, which have affected favorably, or otherwise, the construction of irrigation works generally.

* Memorandum on the Mauri Cunawai dated, 29th January, 1863.

The first of these is the generally undulating character of most of the open country. Totally unlike the wide plains of Northern India, there is probably not a square mile in the whole country absolutely flat or level. While in the Carnatic, the slopes of the country are not much more than 4 feet per mile, they here range from 10 to 20 in the flat portions, and as high as 60 and 80 feet elsewhere. The original cost of storage in Mysore, as also the risks, have thus been proportionably enhanced. The channels drawn from the several anicuts, moreover, for the same reason, command relatively but little ground, the rapid side-slopes preventing their drawing away to a sufficient distance from the river margins.

The second point in which there has always been a considerable disadvantage, is the incoherent nature of the soil, which over the greater portion of Mysore, is chiefly red and sandy, resulting from the disintegration of gneiss. Pure clay is mostly to be found in nests of decaying felspar, &c,—and is necessarily rare. Hence good puddle, that essential in all reservoir work, has been wanting. Leakage is therefore common, and water in motion rapidly works its way, soon destroying all before it. West of Seerah, and throughout the catchment basins of the Huggary and Soolikerray, a decaying metamorphic rock of a crystalline ferruginous character prevails, with a great extent of cotton soil, neither of which are of any use for the manufacture of puddle. The tank bunds here have therefore been formed under great disadvantages.

In the matter of stone, Mysore is highly favored, as the prevailing gneisose rock, where the cleavage is horizontal, splits off readily in large sheets from 3 inches to 2 feet in thickness, by the simple application of heat to the upper surface. By punching small holes, these sheets can by wedging be divided with great precision, into fairly even slabs of almost any dimensions, thus affording at once a most valuable material for all such works, as anicuts, codies [tank waste-weirs] sluices, overfalls, &c.* Stone telegraph posts thus prepared and 25 feet high have everywhere been employed. The natives have apparently used this material from time immemorial, though the ordinary pitching of their tank bunds is, for the most part, formed of rough natural blocks, picked up in the neighbour-

* In the High School, Bangalore, columns 35 feet high and not over 15 inches square have been used of this material. It is also employed for architraves, and for bridge girders up to 11 feet span. Extreme hardness has however prevented its use as dressed stone, excepting under very exceptional circumstances.

hood. Sometimes also they have employed round worn or disintegrating stones, which are of course quite unfit.

To the general excellence of the stone and its universal applicability, may, with possibly the scattered nature of the lime deposits, be attributed the practice of making the stability of all anicuts and over-falls to depend solely on the size and position of the individual blocks used in the work, instead of on the homogeneity and cohesiveness of the mass. This serious constructive error, which has caused endless trouble and expense, will be noticed more particularly further on—meanwhile it appears undesirable to defer longer such observations as I have to offer on the number, construction, and repair of the tanks considered individually, with the best method of meeting the objects proposed by Government.

Tanks.—By the returns of 1853-54, there were 26,450 tanks in Mysore classed as municipal or unirrigating, and irrigating. Of this enormous number there were 4,106 large irrigating reservoirs, 13,737 small, and 8,609 unirrigating, giving over all, about 1 tank per square mile in the gross.

In 7 talooks of Colar, where there are moderate conditions of rain-fall, and no reservoir of extraordinary size, there were I find 3,611 tanks, of which 2,950 were irrigating—the proportion being 1 village, and 1·07 irrigating tank to the square mile. The average quantity of wet cultivation was 10 acres under each, but this is of course not wholly to be depended on.

Turning to the rainless tract above mentioned, taking the talooks of Hossdroog, Davengherry, Cancoopah, Moolcalmooroo, Harnhully, and Boodihaul, in all there were 1,009 tanks registered, the proportions being 0·47 villages and 0·31 irrigating tanks per square mile, while under each of the latter, there were only 2·5 acres of wet cultivation on an average. Allowing the returns to be relatively, though not absolutely, correct, it would thus appear that in these barren famine stricken talooks, there was only one quarter of the wet cultivation in equal surfaces of country, as compared with Colar. While moreover the average of population, was by the last Administration report, 151⅓ per square mile for the whole of Mysore, I find that in these tracts it was only 71.

The classification simply into "large" and "small" is, as affording no clue to capacity or irrigation power, extremely vague; and under the first head especially there are some truly gigantic reservoirs which deserve separation from the rest.

Among these latter, I would specially mention the Nuggur Soolikerray, which has a margin of some 40 miles, a bund 1,000 feet long, 84 feet high, and having a breadth of base of upwards of 600 feet; the Mudduck tank, which is the terminal reservoir at the head waters of the Vedavutty, having a bund 1,220 feet long, 90 feet high, and 660 feet broad at base; also the great Mooteetalau, situated north of Seringapatam, on one of the feeders of the Lokani river, adverted to as follows by Buchanan.* "Two mountain torrents here had united their streams, and forced away through a gap between two rocky hills. *Rama Annuga* stopped up this gap by a mound said to be 78 cubits high, 150 cubits long, and at the base 250 cubits thick. The superfluous water is let off by a channel, which has been cut with great labor through one of the hills, at such a height as to enable it to water a great deal of the subjacent plain, which is three or four miles in extent."

Works of this kind are however a class "*per se*." Originally being natural basins, it was only needed that the gap between the two hills guarding the outlet of the valley, should be filled up, and a good position for the waste-weir secured. Precisely such positions are those of the Coombar Cuttay, and Mauri Canwai situated in the line of hills south of Heerioor, both of which works are now being estimated for.

The ordinary Mysore Tank is, however, a much longer and lower description of work; but on this point I think it better to substitute Captain (now Major-General) Green's remarks for my own, and therefore make no apology for making the following extracts from that Officer's Report of the 9th October, 1846, published in the selections from the Records of the Commissioner's Office :—

"*Tanks.*—There are upwards of 20,000 tanks in the returns, the bunds of which are of every variety of length from a quarter of a mile to 1½ miles. They are, with very few exceptions, faced with a rough stone revetment, having a batter of about one horizontal in two vertical; the stone facing averages from a yard, to half a yard in thickness, and is backed with loose rubble stones, which are together of a thickness equal to that of the large stones in front. Occasionally a lighter description of revetment retains the rear slope of the bund. The breadth of the earthwork is proportioned to its height, which is greatest in the centre of its length. An ordinary bund is about 12 feet broad at top, 60 feet at bottom, and 18 feet high; there are many in every Talook, however, which exceed the above section.

"*Sluices.*—Each tank is provided with from one to two, and sometimes three sluices, by which the water can be let out on to the fields at pleasure. Their position is gener-

* Journey through Mysore. Volume II. Page 82.

ally on a level with that of the bed of the tank, but if any portion of the lands to be irrigated be above that level, one or more of the sluices is placed at a corresponding height. A tank sluice is a large, substantial and not unfrequently an expensive work; it consists of a two yard square brick or stone cistern one yard high, to keep off the sand at the front of the bund, with one or more valves, or plug-holes in a stone at the bottom, from 6 inches to a foot in diameter. The valve is attached to a pole so long, that the top shall never be covered with the water in the tank. It is held in an upright position by 2 or 4 vertical stone pillars from 9 inches to half a yard square, to which horizontal stones are attached, one at top and another midway, down through a hole in the centre of which, the valve rod works, having a stout chain and pin to uphold it when necessary, and to regulate the discharge ; the pressure of the water upon the top of the valve keeps it sufficiently tight, when lowered into the valve hole, to prevent the escape of the water. At the rear of the bund, another cistern of about the same dimensions and usually of brick in chunam is built, three sides of which are furnished with square openings and shutters, to admit of the water being turned off in the required direction. The two cisterns are connected with a tunnel, the length of which depends upon the cross section of the bund through which it is laid, and is generally from 10 to 30 or 40 yards. The vent throughout the tunnel, for the passage of the water, is about 2½ feet high and 2 feet broad. These dimensions are adopted to permit of a man going in to clear away obstructions, and to examine the state of the tunnel occasionally, should anything appear to have gone wrong. The cross section of a tunnel is like that of a massive barrel-brick-drain, but the vent is generally rectangular and cased with granite slabs about 6 to 9 inches thick.

" *Codies.*—In addition to the sluices each tank is provided with from 1 to 4 open masonry outlets, called codies, the gorges of which vary from 10 to 100 yards in width, and by which the surplus water of the tank escapes to other tanks below. As the rush of water over the codies would wash away any but a strong description of work, by which it is confined in its passage from the tank, the codies are necessarily made very substantial with the largest sized rough stones procurable in the neighbourhood ; those of the large tanks rivalling the smaller anicuts on the rivers in the massiveness with which they are constructed, and the brick retaining walls with which they are frequently protected. Codies are generally of a square figure covering as much ground lengthways, as in their width. The front, which breasts the water, consists of a solid rough stone wall from 1 to 2 or 3 yards deep, according to the quality of the soil, and of proportionate thickness. It is furnished with dam-stones, which project a yard and a half, and are let firmly into the top of the wall at 1 yard intervals. The addition of some sticks, straw, and turf placed in front of these vertical stones makes a temporary dam, by which the ryots are enabled, after the burst of the monsoon is over, to retain the water in the tank at a level about two feet higher than they otherwise could have done, and to secure the water for a so much longer period.

"The sides of a cody are protected by wing walls 1 to 2 yards high, of rough stone or brickwork, which contract or approach one another at the ends of the gorge wall, and widen out above and below, forming, as it were, the sides of the funnel of discharge.

" The stones on the lower side of the gorge wall, are usually laid over suitable foundation in the form of a sloping apron, from its top to the bottom of the nullah below, by which the force of the water is broken ; in cases, however, where it is found

difficult to render this (the ancient mode of building codies) permanent, recourse has been had to disposing of the apron stones like a flat pavement at the foot of the gorge wall (whatever be the height of the latter) taking care to have a very solid iron clamped platform of cut stones for the water to cascade upon. Its force is there expended, and it flows gently away from the foot of the gorge wall without having the power to do any mischief; this plan is found most effectual, and has never failed wherever it has been tried.

"The level of the top of the cody, whether of the permanent masonry, or of the low temporary dam now occasionally put above it, is the gauge of the powers of capacity of the tank; above that, the cody is always open and acts as the safety valve of the tank.

"In the nullah, immediately below a cody, is sometimes built another work of rough stone like the cody, and equally large, but which so applied is termed a "cuttay." Taken off, from above the latter, is a channel of irrigation. This is a very good arrangement, when the levels are favorable. The cody retains the water in the tank at its highest safe level; the cuttay below appropriates the surplus water, which the cody has discharged, and which but for such cuttay would be lost. Pouring over the cody in a thin sheet of perhaps a few inches only in depth, the sectional area of the water is fully sufficient to supply an ordinary tank channel of irrigation, and when it ceases, recourse is had to the sluices in the bund which are then opened. The Coonghul great tank, the tank at Heerashay, the Kickary tank, and the Hullaypoor tank at Nunjingode, all first class tanks, have cuttays below the codies of this description; and there are many others in different places. As the surplus water for 10 or 15 days annually is discharged in a great volume over the codies, the cuttays below are then exposed to a great shock from the impulse thereof, and require to be substantially constructed like the river Anicuts.

"As the alluvial deposit, year after year accumulating, gradually raises the beds of tanks, they would in process of time become useless, were not the alternative adopted from time to time of adding to the height of the bunds, which of course involves an enlargement of the cross section generally, as well as the raising of the codies and the construction of new sluices at higher levels than the former ones occupied, when the sand has eventually choked them up.

"Thus, even if no breaches occur, there is a constant yearly increased demand for tank work, and several of the bunds have attained an immense height in the effort to keep them sufficiently above the surface of the water. The upper part or roadways of several bunds in each of the four Divisions, are on a level with the tops of the cocoanut, and even of the more lofty areca, trees in the gardens immediately below them.

The same resource is had recourse to, in discharging the sand from the tank beds, that is adopted for the ejection of that carried into the channels of irrigation from the rivers. But a different season is selected; instead of the close of the monsoon, its commencement is taken, and no sooner is it seen that the monsoon has set in, than the ryots range themselves about the sluice head in the tank, which is at this time shallow, and stir up and agitate the bed, till, reduced to a semi-liquid state, it runs off through the sluice with the water. This, like the opening of the nullah under-sluice, is however but a partial remedy. It is less expensive to raise the bund than to carry away the sand by hand.

"Most tanks receive their supply from the high ground in the neighbourhood, and irrigate paddy fields or gardens immediately below them; but there are exceptions to

this, as numerous tanks are partly supplied by channels winding round more remote hills, and which catch all the rain water flowing down their sides and convey it into the tank. Water-courses or nullahs which are called into existence during a local fall of rain, are also dammed up, and their contents in like manner appropriated to the benefit of tanks. A single tank may possess several feeders of this kind, all of which require to be kept in repair.

"In like manner the fields to be irrigated are occasionally at a distance from the tank, and have channels of irrigation therefrom, including their windings, of from 2 to 30 miles long, and upon the preservation of all of which in proper order, depends the success of the crops. The water of the Soolikerray lake irrigates land at a distance of 30 miles. Other reservoirs of water, not connected with the irrigation, but such as public wells, bowries, cuttays and so forth, which are required for the use of the inhabitants and their cattle, have been extensively restored in every Talook in the country; and the consideration of the Government in directing these improvements of works so essential to the health and comfort of the community, is rightly appreciated and gratefully acknowledged.

"Many of the tanks, aqueducts, anicuts, and channels of irrigation, which had failed during the Rajah's Government, previous to the year 1835, as well as the village reservoirs, have been restored. Others, which were decayed have been efficiently repaired, and the few which were tolerable have been put into perfect order. It may be confidently affirmed that none of the works of irrigation have deteriorated since the transfer, but that their condition has been very greatly improved."

So far as can be judged, in regard to the condition of the tanks in 1846, the description should probably be held to apply, rather to their then state, as compared with what they had been under the previous Native Government, than to their actual condition as tested by that high and efficient standard, which alone could be accepted with the present views of Government, and under scientific direction.

It will I think be conceded, that the area at any time actually under wet cultivation, is the best test of the efficient state or otherwise of the reservoirs, from which the supply of water requisite for that cultivation is derived. At least I know of no other, and have inserted on the next page the following quinquennial return, for the 25 years between 1837-38 and 1861-62, obligingly supplied from the Commissioner's office.

Judging from this, the works are probably now in a more prosperous condition, than at any other time of which we have record, and the increase in efficiency has apparently fairly kept pace with the increased liberality in the expenditure, taking into account the great rise in labor rates of late years.

But when we come to examine accurately their real condition, we find that while admitting fully the progressive advance that has been made, the tanks are in anything but a satisfactory state. Further, that while indivi-

Years.		Acres under wet and garden cultivation.	Expenditure on agricultural repairs other than the Astagram channels.	Average yearly outlay.
From	To		Rupees.	Rupees.
1837-38	1841-42	17,05,150	4,70,178	94,036
1842-43	1846-47	18,49,759	4,32,254	86,451
1847-48	1851-52	20,87,929	5,86,443	1,17,289
1852-53	1856-57	21,60,309	7,00,205	1,40,041
1857-58	1861-62	21,69,040	8,07,619	1,61,524
Total outlay in 25 years, ..			29,96,699	1,19,868

dual repairs have been dealt with energetically and effectually, there has been a clear want of a general plan of action under scientific direction. As a rule, breaches of tanks and anicuts have on their occurrence, been vigorously taken up. But with all these cases, there has not been apparently that thorough sifting of causes, and reference to general scientific principles, which there can be little doubt is equally essential with energetic treatment.

The Executive Engineer of the Bangalore Division reports, that fully half the tanks under him are either breached, or in need of thorough repair. In Chittledroog 285 tanks, or one-third of the registered number, are similarly out of order. In Toomkoor, 530 out of 1,124; in Shemogah, 2,496 out of 4,520; and in Mysore, 705 out of 1,409. Captain Johnson, the most experienced Executive Officer in the Province, states, with reference to the latter district, that three-fourths of the tanks require absolutely necessary improvement, and that one-half are positively unsafe. It is this real condition of matters, with which we have to deal, if, as now determined by Government, the people are to be preserved by all human means from the effects of drought.

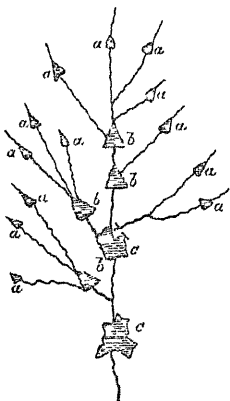
Without a much more complete examination of existing works, and in the absence of detailed estimates, it would of course be quite impossible

to say what would be the cost of the requisite renewals, &c, to the tanks now out of order; but assuming roughly that, in all, 1,500 first class tanks and 4,500 second class require the ordinary outlay now made in dealing with special cases [*i. e.*, about 3,000 rupees for each 1*st* class, and rupees 1,500 for each 2*nd* class tank], the total outlay would probably not fall far short of Rs. 90,00,000.

Looking at the vast amount of patient industry, and even drudgery, devoted by the native cultivators to the preparation of the ground under the tanks for rice cultivation, it must, to ordinary observers, be a strange matter that they never once dream, of giving even an hour's work, to the preservation of the bunds upon which the fruits of their labors entirely depend. Not only however is such actually the case, but with stranger fatuity still, they appear to do all in their power to render the bunds insecure. They cultivate against orders close under the foot of the embankment, they dig roots, cut firewood, make foot-paths in every direction, drive over their cattle and carts when possible, and in a hundred other ways loosen the soil and weaken the work. Not satisfied with this they, against the most positive orders, temporarily build up the waste-weirs between the dam stones, with a view to increase the capacity of the tank, and thus almost insure the work breaching in case of flood. This is no imaginary picture, as I have reason to believe that several of the late breaches to tanks have occurred from this reckless inattention to orders. But beyond all this, there are criminal acts, such as cutting bunds, &c., to cause breaches, with the apparent object of reaping the advantage; *First*, of the expenditure which will probably take place in repairing the work; and *Second*, in the abundant yield of the dry crops, sown in the rich loamy bed, while the work is out of action.

It is, of course, beyond my province to suggest what direction legislation should take in order to deal effectually with such offences; but I may be permitted to observe among other matters, that the universal safety of the bunds over which our high roads have been carried, points to the desirability of making the top of each tank bund, into a well formed level village path-way, with the preservation of which the village authorities should be specially charged, as also with the absolute prevention, under specified penalties, of all acts like those I have described, directly tending to the injuring of the work.

Regarding the general plan of action for bringing all the works up to

standard, there are so many points of constructive detail involved, that I must limit myself here to one of prime importance. The side sketch shows an ordinary stream under the tank system. Population taking possession of the high grounds, constructed the small tanks *a*, *a*, *a*, *a*, and after these minor feeders had been thus brought under regulation, they then throw bunds up lower down forming other and larger tanks *b*, *b*, *b*, *b*, and eventually first class tanks *c*, *c*, further down still in the main stream. The tanks *a*, *a*, *a*, are of course individually of small importance and indeed so are the tanks *b*, *b*. The villages connected with them are also small, and unable to make themselves heard. As sometimes occurs, with excessive floods, the whole chain of tanks goes together (many of the smaller, and earlier constructed tanks, having no provision for discharging surplus water) and sweeps with it the terminal tanks *c*, *c*. These latter, as relatively very important in a revenue sense, and usually connected with large communities, have their repairs attended to immediately, while those higher up the valley (*b*, *b* and *a*, *a*, *a*) are left in the breached condition. The slightest reflection will show that this is the reverse of a really scientific management; and that as the safety of *c*, *c*, depends on the working condition of those higher up, these latter should be seen to first. An accurate scientific determination of the capacity of the waste weirs, height of the bunds, &c., of each and all of these, is consequently a prime essential of safety, for the greater and more important works below.

In concluding this notice about tanks, I shall state briefly what works it is proposed to bring forward in the next Budget, not so much as forming the commencement of the systematized work which I have ventured to recommend, but as an endeavor to meet the most urgent requirements of the rainless and barren tract of country which has suffered lately the horrors of famine as before adverted to.

I hope to be able to bring forward definitely the long discussed project [amounting say to Rs. 9,00,000] for the Mauri Cunawai tank, and Estimates are, it is understood, nearly ready for the Coombar Cuttay [Rs. 1,00,000] with 9 restorations of reservoirs in the Chittledroog Division,

amounting perhaps in the aggregate to Rs. 70,000. This, in addition to the ordinary tank repairs by Civil Officers, would afford, for the time being, great relief to the sufferers, while proving very remunerative to the State. The latter point will of course be fully stated in sending up the detailed Estimates.*

The only other project of large dimensions is that of the Mysore Soolikerray or Cundly tank, a great terminal reservoir on one of the feeders of the Shimsha river, which, though commenced centuries ago by the natives was never finished. The Estimate may be 1 lakh, or Rs. 1,20,000, and is understood to be well advanced.

[*To be continued.*]

* The remunerative returns promised on the usual tank repair Estimates, passing through this Office, vary from 20 to 40 and even 50 per cent. on outlay, but there is no absolute proof that these per centages are realized, and as in the *first* place the cost of maintenance and risk is left out of the calculation, and in the *second* a general scheme, embracing all the tanks of the country, must of necessity take the bad with the good, the profits though undoubtedly very remunerative, must be struck at a lower figure, and probably on the average would not much exceed net 10 per cent. all round.

No. CXLII.

BRICK-MAKING—NEAR ROORKEE.

Notes on the Brick Kilns at Mahewah, on the Ganges Canal. By CAPTAIN F. D. M. BROWN, V.C., *Assistant Principal, Thomason College.*

THE village of Mahewah is three miles from Roorkee, at the upper end of the great Solanee embankment, by which the Ganges Canal is carried over the valley of that river. A large brick yard was here formed for the supply of bricks to the canal works, and as this has lately been remodelled on the English system of moulding and burning, it is thought that some details of the working and cost may be acceptable. I am indebted to T. Marten, Esq., Superintendent of Materials, Ganges Canal, for the ample information he has given me of the details, and of the results of his experience in brick-making.

The earth, for making the bricks, is prepared from the spoil bank of an old cutting; down the middle of this bank a deep trench has been dug, which fills with water in the rains, and is supposed partially to temper the clay.

The *Pug-mill* [*Fig.* 1] is sunk $2\frac{3}{4}$ feet, so that the clay may be tilted in, by an easy ramp leading to the top, and at the same time the men below may be able to lift the prepared clay to the level of the ground. The casing of the mill is made of $\frac{1}{4}$-inch sheet-iron, 4 feet high and 3 feet diameter at top and bottom. The casing is raised 12 inches from the bottom of the pit, and half the mill is bricked up; the clay oozing out of the opening thus formed on the unbricked side. The shaft is made of $2\frac{1}{2}$-inch square bar iron, having 7 iron blades, 4 inches × $\frac{1}{2}$-inch, and supported at the top on three sides by T iron struts, the fourth being open to leave room for

tilting in the earth. The uppermost blade is $1\frac{1}{4}$ feet from top of iron sheeting, and inclined at about 25°, the angle increasing with each blade, the lowest one being 70°. The lever is 15 feet long, and worked by a pair of bullocks. This mill is sufficient to supply six tables.

The *Moulding tables* are $6\frac{1}{4} \times 2\frac{3}{4} \times 2\frac{1}{2}$ feet; to each is fixed the lower part of the mould [*Fig.* 2], and an iron basin holding water in which the wooden strike is kept. The *strike* should be made of deodar or some fir wood, and a new one issued daily to each table. At right angles to the table and to the left of the mould is the *page* [*Fig.* 3], consisting of two parallel $\frac{1}{2}$-inch rod iron bars about 7 inches apart, bolted at one extremity to the frame of the table, and at the other to an upright plank, and supported at the centre by another upright plank. Under the table is a strut, immediately below the centre of the mould, to prevent any "kick" or spring from the table. This should be looked to and be wedged up every day.

The *Brick mould* [*Fig.* 4] is of $\frac{3}{16}$-inch iron, $10 \times 4\frac{7}{8} \times 3\frac{1}{2}$ inches, inside measurements; when put on the table it rests on the four adjusting screws A, A, &c. [*Fig.* 2], which are so regulated that the bricks turned out are the required thickness, $3\frac{1}{8}$ inches. The tops of these screws, as also the parts where the mould rests, become indented from the constant blows on them and might, with advantage, be steeled. The bottom of the mould, which is also iron, has a die upon it, $8 \times 2\frac{1}{2}$ inches, raised $\frac{1}{8}$-inch, this makes an indentation in the brick which is intended to hold the mortar, and enables the mason in building to draw the joints very fine. To mark the brick, the letters G. C. (Ganges Canal) are raised $\frac{1}{8}$-inch on the die. A wet brick, as turned out of the mould, weighed 4 seers 12 chittacks; the sun dried, 3 seers 12 chittacks.

Moulding and Stacking.—The man who prepares the clay into suitable lumps for the moulder, must be careful to make each lump solid, without cracks, by repeatedly thumping and pressing it on the table, as these cracks form blemishes in the moulded brick. At the same time he must be careful in keeping his part of the table well sanded.

The mould is cleaned first with water and then sanded, the die being cleaned when necessary with a country made horse-brush. The moulder takes one of these prepared lumps in both hands and, raising it above his head, throws it into the mould; he then clears off the superfluous clay with his hand (taking care to leave the full amount required) and pressing the remainder into the mould, strikes it with a small wooden straight edge;

the strike is cleaned, as it is put back into the water, against the sharp edge of the iron bowl.

Having moulded the brick, he places the mould sideways, with a smart blow, on the bars of the page, which, by their spring shake the brick loose; he then places a board 12 × 6 × $\frac{1}{3}$ inches against the lower side of the mould, and putting the board flat on the bars of the page, with the brick and mould resting on it, removes the mould and slips the board, with brick upon it, along the bars of the page to make room for the next.

The bricks are sanded and carried away on the boards in hack-barrows [*Fig.* 5] which hold 26 (viz., 13 on each side). The hacks are on terraces, raised 9 inches from the ground, and covered with a layer of flat bricks laid dry; they are three bricks broad, so as to hold two rows, and long enough to hold the day's work of a moulder, as putting on a second course the same day spoils the shape of the bricks. A moulder can make 1,000 bricks per day; and when working by contract, 1,500.

In hacking the bricks they are lifted from the hack-barrow between two pallets, viz., the original one below the brick and another put on the top, by this means the shape of the brick is not injured, they are placed at once on edge, with the distance equal to the thickness of a pallet between them, and each brick to break joint with the one below; the top of each row must be sanded before the next is put on.

The number of hands employed at six tables are:—

3 men to dig, prepare earth and pump water.

3 „ to wheel prepared earth into the pug-mill.

2 „ to take the earth as it comes out of the pug-mill and place it in lumps on the level of the ground.

2 „ to carry the lumps from pug-mill to moulding tables.

6 „ (one standing opposite each moulder) to prepare the earth in suitable and compact lumps for moulder.

6 „ moulders.

6 „ (one to each table) to carry the bricks away and hack them.

One pair of bullocks to work pug-mill.

2 boys to turn the bricks on their backs while drying.

Total, { 28 men, 2 boys, } and one pair of bullocks.

The moulders are paid Rs. 6 per mensem, the other laborers from 4 to 5; boys, from Rs. 2 to 3.

Kilns.—The floors of the kilns are level with the ground, the flues and ash-pit are sunk 4 feet. The flues face N. and S., that is, at right angles to the direction of the prevailing wind.

The fuel is thrown on to the iron bars of the flues through an iron door [*Fig.* 6], which must be always kept shut, except when supplying the fuel, as an immense amount of heat is lost if left open; and this the stokers are very apt to do, unless closely watched as the doors are difficult to open. By putting an iron ring on the door instead of the knob handle, as at present, and opening with a detached hook, this difficulty might be obviated.

The sill of the doors is raised 6 inches above the top of the grating.

There are two sizes of kilns in use at Mahewah. *Figs.* 6, 7, 8, 9, 10, 11, 12, 13, give all the dimensions of the larger size as built at present; but only one or two kilns of this size have as yet been fired. From the experience gained in burning these, it is proposed to make the following alterations in the next ones built.

The two flying buttresses on each side will be removed, as they make the stoke-hole so hot towards the end of the burning that the stokers can hardly remain there; at the same time the walls, which are already too thin, are to be made 4 feet 6 inches at bottom and 3 feet at top, and buttresses left only at the four corners. The flues are to have only three sets of bars each (with 9 bars in each set), the remainder of the flue being sloped up (shown in every second one, *Fig.* 7), as with four sets of bars the flue is too long to stoke properly.

This kiln holds 1,65,000 bricks. The walls are built of peela bricks set in mud and well "leped," both inside and out. The kilns now burning are converted from Sindh kilns, which were already standing, and several dimensions had to be adapted to circumstances; one chief point being that the end flues are put too far in from the side walls.

The small kiln, built on Mr.* Hickmott's plan (measuring 30 × 18 feet and 14 feet high inside) has the walls 4 feet thick up to the level of the ground, and 3½ feet thick to the top: the two long walls have a slope of 1 to 12 inwards, which appears to be a capital construction, not only in strengthening the walls but by keeping in the heat. There are only four flues, 5½ feet apart, the two end ones being 2¾ feet from the side walls. Below the door of the flue is an iron damper to regulate the draft; it has been found that when these are shut, the heat becomes so great

* In charge of the large Government Brick-yard at Akra, near Calcutta.

in the flues that the bars of the grating are bent and rendered useless, and the arch bricks fuse; they have therefore been discontinued in the new kilns. The same effect is produced if the ashes are allowed to accumulate in the ash-pit, which must be kept constantly raked out.

This kiln holds 65,000 bricks.

The price of the iron-work at the Roorkee Workshops is as follows:—

1 Fire-door, at Rs. 15 each.
1 Fire bar, 7 seers 6 chittacks, at Rs. 9 a maund.
1 Angle iron support, 12 seers 8 chittacks, at Rs. 9 a maund.
1 Iron brick mould, at Rs. 1-8 each.
1 Table complete (including table, die for brick mould and page), at Rs. 102.
1 Pug-mill (iron work), at Rs. 175.
1 Hack barrow, at Rs. 28.
1 Earth barrow, at Rs. 12.

In *loading the kiln*, the bricks for the first 11 courses are laid on edge close together in parallel walls [*Fig.* 14], with 5 inches interval between each wall and 5 inches between the inside long wall of kiln and the first wall of bricks. Where these parallel walls cross the flues, the bricks are corbelled out [*Fig.* 15] meeting in the 11th course. As it is most important that these openings should be properly built (as their falling in smothers the fires and causes every conceivable damage), a triangular wooden centering is used to insure regularity and proper bond. Another important point is that, the parallel walls should be built perfectly plumb and straight, as any unequal pressure coming on them when the bricks are soft, from the intense heat, causes the wall to give in that direction, and the bricks above of course fall in. The centre wall is one or two bricks thick (according to the room left) with no opening for flues; the bricks, however, are placed on edge not quite touching, so that the communication between the sets of flues on each side is not entirely cut off.

In the 12th course [*Fig.* 16] the bricks are laid on edge, on the parallel walls, with the interval of a brick between each, and the openings between the walls are bridged over by bricks on edge, alternating with those on the wall.

The 13th course is laid on edge at an angle of 45° to the walls of the kiln, with the interval of about an inch between each brick.

The 14th course is laid on edge, parallel to the side of the kiln, leaving intervals of 1 inch; the upper courses are built each at right angles to the one below, the intervals getting smaller till the last 5 courses, in which the

bricks are placed close together, and a top course of bricks laid flat; over all this is put two layers of oopla.

If whilst loading there is any chance of rain, light king-post trusses, made of angle iron, are thrown across the top of the kiln, these are connected together by stout ropes and bamboos and small choppas (12 × 10 feet) placed on them.

Soft woods and dák (which is generally more or less decayed) are a bad description for burning, as they smoulder and do not give a brisk fire; of keekur, sissoo, or any hard wood, less than three-fourths the quantity as compared with the soft wood is required.

In *firing the kiln*, the arrangements are as follows:—

Commence firing in the evening with chips, just enough to warm the kiln (1 man to 3 doors). On the second evening, this small fire should be pushed back to the end of the flues. Third evening, the fire (still kept very low) is brought to the front again. Fourth evening, the firing is forced on vigorously; 2 men are now put on to every 3 doors, and the firemen are relieved every 12 hours. During the night, go to the top of the kiln, and should the fire be breaking out at any place, it must be immediately stifled by throwing a few baskets of ashes over the place where it is doing so. This must also be done on the next two nights, as that is the only time you can see how the kiln is burning.

The fires are kept up as strong as they can be till all the wood is burnt, the quantity, under ordinary circumstances for the small kiln, being about 10,000 cubic feet or 2,000 maunds of dák wood, or three-fourths of the same weight of sissoo, keekur, babool, or any hard wood; taking the latter at 4 cubic feet to the maund. This, if fired properly, will take 3 days and 3 nights of slow, and 3 days and 3 nights, of vigorous, firing. When the kiln is burnt it looks at night from the top, like a molten mass, and appears almost transparent.

When the firing is stopped, the top of the kiln should be covered at once with 6 inches of ashes. The doors are left ajar for 12 hours, after which they are opened, and the whole of the openings carefully bricked up.

In the first kiln burnt, the openings were bricked up at once, and the bars and supports of the grating were found doubled up and rendered useless; whereas four kilns have now been closed in the manner recommended, and the grating bars are still good. Mr. Marten says that the bricks are not injured in the slightest by not bricking up at once; I think that the grating might be so arranged that it could be pulled out, like a drawer, on

to a travelling truck, and removed to a flat platform to cool; or some other arrangement might be made for removing the grating, as the air, though slightly heated by the remains of the fire, yet striking on the bricks when at such a high temperature, must make them more brittle than they otherwise would be.

The kiln should on no consideration be opened under 15 days, and the longer they are left, of course the better the bricks will anneal.

The average weight of 4 pucka bricks after exposure to the cold weather rains, was 3 seers $10\frac{5}{8}$ chittacks each; and after soaking for 24 hours in water, 3 seers $14\frac{5}{8}$ chittacks; average of absorption, 4 chittacks, or little more than $\frac{1}{15}$ of its weight. I then placed the bricks in the sun, tilted up on a zinc roof for seven perfectly dry and cloudless days in April, and found that their weight averaged exactly the same, 3 seers $10\frac{5}{8}$ chittacks, showing that they had not absorbed more than a normal amount of moisture at the time of first weighing.

Another pucka brick straight from the kiln, weighed 3 seers $9\frac{5}{8}$ chittacks, after soaking it in water for 15 minutes, it weighed 3 seers (all bubbling having ceased after about 13 minutes). After 6 days' immersion, it weighed 3 seers $0\frac{7}{8}$ chittacks, showing that a brick has absorbed nearly all the water it is capable of doing as soon as it ceases to give off bubbles, and that a quarter of an hour is ample time for soaking bricks before using. On soaking pucka bricks straight from the kiln, they absorbed on an average $6\frac{1}{4}$ chittacks; while those which have been exposed to the weather absorbed only 4 chittacks of water, showing that these bricks naturally absorb about $2\frac{1}{4}$ chittacks from the atmosphere in ordinary weather.

Out-turn.—As these are the first kilns of the kind that have been burnt at Mahewah, the results must be considered only as experimental:—

RETURNS OF SMALL KILN AT MAHEWAH.

Number of firing.	1st class brick.	2nd class brick.	Half brick.	Peola.	Jhama brick.	Pucka. roora.	Roora for soorkee.	No. of maunds of wood.	Description of wood.
						c. ft.	c. ft.	mds.	
1	21,600	11,000	...	13,000	3,300	300	200	950	Sissoo and babool.
2	13,200	12,600	500	28,860	...	500	45	1,200	Dák.
3*	4,500	7,000	...	55,000	...	...	100	1,400	Do.
4	45,800	8,500	...	5,400	2,700	...	...	2,500	Do.
LARGE KILN.									
...	92,000	2,800	...	36,000	8,000	60	...	...	

* This kiln spoiled by rain.

There is no doubt when these kilns are once fairly started, that the out-turn will be far in excess of that here given.

Cost.—The bricks turned out from these kilns are of excellent quality, being well burnt and well shaped. It is impossible to estimate their exact cost without further experience; but the following, taken from the data above given, may be considered an approximation; though, doubtless, the cost will be reduced when the brick-yard is in full working order.

Approximate Estimate of the cost of a small Hickmott's kiln, to hold 65,000 *bricks.*

c ft		RS.
7,900	Peela brick in mud, at Rs. 5 per 100 cubic feet, ...	395
6,400	Excavation, at Rs 2-8 per 1,000 cubic feet, ...	16
No		
8	Iron doors, at Rs. 15 each, ...	120
32	Angle iron rests, 10 maunds, at Rs. 9 a maund, ...	90
216	Grating bars, 40 maunds, at Rs. 9 a maund, ...	360
	Total Rupees, ..	981
	Contingencies, at Rs. 5 per cent. ..	49
	Grand Total, Rupees, ..	1,030

Moulding.

6	Moulders, at Rs. 6, ...	36	per month.
15	Men, at Rs. 5, ...	75	
7	„ at Rs. 4, ...	28	
2	Boys, at Rs. 3, ...	6	
2	Bullocks, at Rs. 15, ...	15	

160 = cost of moulding 1,56,000 bricks, *i. e.*, 1,000 bricks per moulder per day of 26 working days—or about 1 rupee per 1,000.

Approximate cost of one kiln of bricks.

	R.	A.	P.
Moulding 65,000 bricks, ...	66	0	0
$\frac{1}{10}$ cost of kiln for each burning, ...	103	0	0
Loading and unloading kiln, ...	15	0	0
2,500 maunds of wood, at Rs. 12 per 100 maunds, ...	300	0	0
Wages of firemen, ...	9	0	0
Plant, supervision, &c., ...	50	0	0
Total Rupees, ..	543	0	0

Taking No. 4, or the last firing (in table of results), as the least out-turn that may fairly be expected from the small kiln (the other three being experimental only) and 2nd class bricks as equal to half, and peela and jhama to one-fifth, the value of 1st class bricks, then the whole out-turn will be equal in value to $45,800 + \frac{8,500}{2} + \frac{5,400 + 2,700}{5} = 51,670$ 1st class bricks.

Hence the approximate cost of the bricks may be put down as—

10·5	rupees per 1,000 for	1st class bricks.
5·25	„	2nd „
2·1	„	Peela and jhama.

F. D. M. B.

No. CXLIII.

THE TELEGRAPH TO INDIA.

Abridged from the Minutes of Proceedings of the Institution of Civil Engineers for 1865-66. By Sir Charles T. Bright, M.P., M. Inst. C.E.

The junction of the European and Indian telegraph systems, and the extension of a line from Rangoon to China and to Australia, by way of Java and Timor, have engaged the attention of telegraphic Engineers for some time past. The line between Europe and India has now been completed, and a large number of messages are daily sent to, and received from, the chief cities of the Indian Empire.

In considering the best mode of constructing a telegraph to India, two routes present themselves for selection, each possessing certain merits and disadvantages. By laying a submarine cable from Malta to Alexandria, and thence by way of the Red Sea and the Arabian coast to Kurrachee, nearly the whole of the line would be submerged, and would thus be free from the risk of interference at the hands of the natives, to which a land line, passing through Asia Minor, Mesopotamia, and Persia, would be subject.

In 1858, a company was formed, under a guarantee from the Government, and a submarine cable was laid from Suez to Aden and Kurrachee; and there is little doubt, that had the route been carefully surveyed, and had the cable been more substantial and better insulated, the line might have worked well for many years. It should, however, be borne in mind, that at the date when the cable referred to was designed and manufactured, the conditions requisite for carrying out works of the kind had not been so

clearly established as they are now, nor had the coating of the conducting wires with insulating materials, attained the high degree of excellence which it has since reached.

While the Red Sea line was in course of construction, the Turkish Government was engaged in erecting a line of telegraph, between Constantinople and Bagdad, passing from Scutari, through Angora, Diarbekir, and Mosul. This line, and its extension to the head of the Persian Gulf had been urged for a long time by Her Majesty's Government, who appreciated the importance of two distinct telegraphs to India. On the failure of the Red Sea line, steps were taken, after a survey by Colonel Goldsmid, to extend the Indian land telegraph in a westerly direction, along the Mekran cost, and for ascertaining the feasibility of erecting land lines through Mesopotamia and Persia, to meet the Mekran telegraph, at Gwadur or Churber. With the latter objects in view, the late Colonel Patrick Stewart, R.E., was sent from India on a special misssion to Persia. He arrived in England in the summer of 1862, at the same time that Mr. Latimer Clark, M. Inst. C.E., returned from a careful examination into the state of the cable between Suez, Aden, and Kurrachee. The result of Mr. Clark's investigation showed the impossibility of restoring the Red Sea and Arabian line, and Colonel Stewart reported against the reliability of a land line along the coast of the Persian Gulf.

A submarine cable from the head of the Persian Gulf to Gwadur, the most westerly point to which it was then found practicable to extend the Indian land telegraphs, was therefore determined upon by the Indian Government, in connection with a land line to be erected, with their assistance, by the Turkish Government between Bagdad, Bussorah, and the mouth of the Shat-el-Arab, and with lines to be constructed by the Persians, from the Russian frontier to Ispahan, Teheran, Shiraz, and Bushire, with a cross connecting line, between Bagdad, Khanakain, and Teheran. It was afterwards resolved, in consequence of the workmen on the Mekran land telegraph being molested by the natives, to continue the submarine line, from Gwadur to Kurrachee. Colonel Stewart was appointed to direct the carrying out of this great length of line; the engineering and electrical superintendence of the submarine portion of the work, and the submersion of the cable, being intrusted to the Author and Mr. Latimer Clark.

To allow of a high speed of working, without any excessive expenditure upon the conductor and insulator, it was determined to divide the line into

sections, with a station at Gwadur on the Mekran coast, another near Cape Mussendom on the Arabian coast, at the entrance to the gulf, and a third at Bushire, on the coast of Persia. The soundings and "bottom" in the Persian Gulf are well known, through the careful surveys of the officers of the Indian navy. The character of the bottom is, however, of so much importance in regard to the permanence of a submarine cable, that a special survey was made by Lieut. A. W. Stiffe, Assoc. Inst. C.E., formerly of the India navy. The soundings between Gwadur and Fao are exceedingly favorable for the deposition of a cable, being such as to allow of the cable being laid at a general depth of from 35 fathoms to 60 fathoms, and the bottom being principally composed of sand and soft mud. Between Gwadur and Kurrachee, the bottom is less favorable, being in some places rocky and irregular.

Such being the conditions tc be provided for, the core, composed of 225 ℔s. of copper, and 275 ℔s. of gutta percha per nautical mile applied in four coatings, with alternate layers of Mr. Chatterton's compound between the coatings and next to the copper wire, was ordered in November 1862, from the Gutta Percha Company. In the following month, a contract was entered into with Mr. Henley, of North Woolwich, for applying the outer covering, consisting of a serving of hemp surrounded by twelve galvanized iron wires, each ·180 inch in diameter. The cable, thus covered with iron, was then coated with two layers of a bituminous compound, composed of mineral pitch and silica, with a small proportion of Stockholm tar, applied alternately with two servings of hemp laid in opposite directions; the whole being passed under heavy rollers while in a plastic state, the outer covering being thus pressed between the iron wires, and into a solid mass. By the proper application of such a coating, the outer iron wires of a submarine cable are preserved from oxidation for a long period, and the cost of the materials employed and of their application, is very trifling compared with the total value of the cable, and its increased durability. For the shore ends, a larger cable was constructed, the outer iron wires being ·300 inch in diameter. A special length of extra heavy shore end, with outer wires ·380 inch in diameter, was made also for use at Bushire.

In the early construction of submarine cables, the conductor was formed of solid wire; but since 1856, when a strand of seven wires was adopted, in the cable laid between Cape Breton Island and Newfoundland, the latter form has been generally used, as there is much less danger of the conductor

being broken. There is, however, the disadvantage attaching to the strand form, that the amount of surface, compared with area, being increased, the retardative effects of induction are proportionately experienced. To obviate this defect, Mr. L. Clark devised, in 1858, a conductor built up of segmental copper wire, and an outer tube was afterwards suggested by Mr. Wilkes. The result of experiments upon this form of conductor, compared with a strand made of the same copper and of the same gauge, showed that the segmental conductor preserved equal mechanical properties, coupled with the best form for electrical requirements.

The respective merits of gutta percha, and of its various combinations and modes of application, as compared with india rubber, whether pure, masticated, or vulcanized, have been so warmly discussed at the Institution and elsewhere, that the propriety of adopting gutta percha for use in a warm climate, may be considered, by some, to be questionable. The examination of the Red Sea line, however, demonstrated most distinctly, that there is nothing to prevent the use of gutta percha in a warm climate, if proper precautions are taken; while on the other hand, there is, as yet, no experience of any other insulator which has been shown to be successful on a practical scale and for a sufficient length of time, to induce confidence in its durability.

The joints made in the insulating material during manufacture, and in the finished core, have always been the subject of considerable anxiety to those engaged in the supervision of submarine telegraphs; as although the loss on a single joint may be so small as hardly to affect the tests obtained upon a considerable length, yet dearly-bought experience has shown, that the defect may contain within it the seeds of a serious fault hereafter. To insure the highest attainable perfection in this important part of the manufecture, a plan was adopted, at the suggestion of Mr. Latimer Clark, which will be readily understood by reference to [*Fig.* 1] of the Plate. A gutta percha trough, about 18 inches long, and 1 foot deep, containing water, is insulated from the ground by four legs of vulcanized india rubber, or preferably, by suspending it from the ceiling by gutta percha cords. The joint under examination is immersed in the water, and a battery of high tension (A) is connected to the copper conducting wire for five minutes, and all the electricity that escapes through the immersed joint during this time, passes into the insulated tank of water. To increase the capacity of the tank for storing up electricity, it is connected with an electrical condenser

(B), consisting of a great number of talc plates, coated on both sides with tinfoil, and having the same electro-static capacity as 1 mile of the cable. The escaping electricity accumulates in the condenser for the given time, and is then suddenly discharged through a delicate suspended needle galvanometer (C), and the number of degrees of the deflection furnishes an exact measure of the quantity of electricity passed through the insulator at the joint. In testing the joints in the Persian Gulf cable by this system, every joint was rejected and cut out whenever it gave less resistance than 40 feet of the core. Newly-made joints were found, almost invariably, to test perfectly, and it was only after at least twenty-four hours' immersion, that a reliable test could be taken. The advantage of this system (which was employed at the Gutta Percha Company's works, and at Mr. Henley's factory) will be apparent from the fact that thirty defective joints were rejected and replaced.

In testing the conductivity of the conductor, its resistance was taken by means of a Wheatstone's electrical balance. The lowest limit of specific conductivity allowed for the copper was 76, that of pure galvanoplastic copper being taken at 100. An electrician was employed at the copper wire manufactories to see that none below that standard was supplied, and an extra price per pound was paid, *pro rata*, for all copper having a higher specific conductivity than 81. The mean conductivity of the whole cable was thus raised to 89·14. In many of the older submarine cables, which were laid before this point had received attention, the conductivity was as low as 30 and 40.

Previous to any tests being applied to the core at the Gutta Percha Company's works, the coils were immersed in water at a temperature of 24° centigrade, and the water was steadily maintained at that temperature for at least twenty-four hours. The resistances of the coils, which were in lengths of about 3,000 yards, were carefully recorded and tabulated, and formed an important check to the temperatures shown by the thermometers in the cable tanks, during the sheathing of the core. The coils were then removed to Mr. Reid's pressure cylinder, being still maintained at the temperature of 24° centigrade. The insulation of the coils was next taken with a battery of five hundred Daniell's elements. They were afterwards subjected to a pressure of 600 lbs. to the square inch, and the insulation test was repeated. The lowest standard of insulation admitted was specified to be such, that each nautical mile of cable should give a resistance of

115 millions of Siemens' mercury units, or 109·9 millions of British absolute units. The average resistance of the whole core, at 24° centigrade, was 192·8 millions of British absolute units. The insulation, of course, improved under pressure, the gain being generally about 16 per cent. It was observed also, that irrespective of temperature, all the coils improved greatly by time. Coils, which when first tested gave a certain resistance, would, after six or seven months, give an increased resistance of 100 per cent. and upwards; so that unless the age of a coil be specified, the mere resistance test is, to some extent, fallacious. Each coil was subjected to a time test, by charging the core with a battery of about forty-eight cells, leaving it disconnected for one minute, and then measuring the amount of loss which had been sustained during that time by leakage; the amount of charge remaining was usually from 50 to 60 per cent. of the original charge. The absolute inductive capacity of each coil was also taken and recorded.

In the absence of a determinate unit of inductive capacity, or quantity of electricity, condensers were employed, formed of plates of mica, coated on each side with tinfoil, and having a standard capacity equal to that of 1 mile of the Persian Gulf core; these have been found in practice very permanent and extremely convenient for use. The measurements were taken after one minute's electrification, by observing the swing of the suspended needle of a galvanometer; and the extreme variations in the several coils did not exceed 8 per cent. above or below the average capacity. From these data, when tabulated, it was easy to ascertain the inductive capacity of any portion of the cable, with such accuracy, that in one interruption which occurred during the laying of the cable, from the copper wire having broken within the gutta percha, the distance of the fault which was calculated at 92·33 miles, proved to be actually at the distance of 92·4 miles. [*Figs.* 2 and 3] illustrate this system of testing.

During the manufacture of the core, advantage was taken of the facilities offered at the Gutta Percha Company's works, for trying a series of experiments, as to the effect of temperature upon the conducting power of gutta percha and india rubber. It had long been known, that the resistance of these substances varied greatly with changes of temperature; but the exact law had not been hitherto satisfactorily determined. To endeavor to ascertain this, four coils of the core manufactured for the Persian Gulf cable were lent by the Indian Government. These were immersed in an iron

tank, containing about 1,200 gallons of water. The tank was thickly felted on the exterior, and facilities were provided for heating the water uniformly, by steam pipes. The coils were each 1 mile in length, and were first reduced to the temperature of 0° centigrade, by the admixture of ice, and were maintained at this temperature for three days, the water being kept incessantly agitated. The resistances of the copper and gutta percha, and the inductive capacity of the core were then taken. The temperature of the water was next raised gradually, and the measurements were repeated at every 2° up to 38° centigrade. The time occupied in the experiments was thirty-three days, during which nineteen series of observations were taken, the water being kept in constant agitation during the whole period.

From the mean results of these experiments, the following formula has been obtained:—

$$R \times \cdot 8944^t = r$$

where R is the resistance at any given temperature, t the increase in degrees centigrade, ·8944 a constant deduced from experiment, and r the resistance at the higher temperature.

The resistances, when plotted, from a logarithmic curve, are shown in [*Fig.* 4]; and for the purpose of comparison, a curve calculated from the above formula is shown in juxtaposition.

The numerical values, as found by experiment, and calculated from the above formula, are given in the following table:—

Temperature (Centigrade).	Resistances obtained by Experiment.	Resistances calculated by Formula.	Temperature (Centigrade)	Resistances obtained by Experiment.	Resistances calculated by Formula.
0°	100·00	100 00	20°	8·43	10·74
2	84·14	80 00	22	6 82	8·59
4	64·66	64·00	24	5·51	6 87
6	47·65	51·20	26	4·47	5·50
8	37·15	40·96	28	3·51	4 40
10	28·97	32·77	30	2 99	3 52
12	23·18	26·22	32	2 48	2·82
14	16·89	20·97	34	1 92	2·26
16	14·37	16·78	36	1·68	1 80
18	11·05	13·42	38	1·43	1·44

It is probable that the coefficient ·8944 will vary slightly with different samples of gutta percha; and from some tests of the core of the Atlantic cable now under construction, kindly furnished by Mr. Willoughby Smith, it would appear that the formula $R \times \cdot 9029 = r$ would apply more nearly to the Atlantic core.

The experiments on temperature were extended to cores of vulcanized

india rubber manufactured by Mr. William Hooper. The absolute resistance of this material is well known to be much greater than that of ordinary gutta percha; but its variations of resistance under changes of temperature, are similar in character to those of gutta percha. Between 0° and 38° centigrade, the resistance of gutta percha decreases seventy times, and that of several samples of vulcanized india rubber, from sixty-three to thirty times, depending on the purity of the material. The curve of variations appears to be a logarithmic one, like that of gutta percha, and a similar formula is applicable.

The coils, after being accepted at the Gutta Percha Company's works were forwarded to Mr. Henley's factory, where they were deposited in a tank of water, and again tested for insulation. The hempen serving over the core, and the outer galvanized iron wires, were applied in the usual manner without any novelty in the machinery calling for special remark.

The external protecting coatings of the bituminous compound were laid on by means of an elevator, driven from the closing machine, so that when the machine stopped, the supply of the hot compound ceased. The completed cable was immediately coiled into tanks filled with water, which were under cover, and where it was continually tested.

The manufacture of the core, by the Gutta Percha Company, was commenced on the 3rd February, 1863, and was finished by the 23rd October following: that of the outer covering by Mr. Henley, was commenced on the 20th February, and was completed on the 10th November, in the same year.

The following are the lengths and weights of the several forms of cable made:—

	Lengths in Nautical Miles.	Weight in Tons.
Main cable, ...	1,172	4,336
Shore cable, ...	50	500
Extra size shore cable, . .	12	192
Total, . .	1,234	5,028

This quantity of cable was coiled on board the following vessels, between the months of July and November, 1863, each ship taking her departure for Bombay as soon as loaded.

Names of Ships.	Ships' Tonnage.	Miles of Cable on Board.	Weight of Cable.
Assaye, ...	1,598½	367·98	1,399·34
Tweed, ...	1,608	349·39	1,328·26
Marian Moore, ...	1,036	174·92	647·20
Kirkham, ...	1,061	187 61	734·20
Cospatrick, ...	1,199	142 10	799·00
Amberwitch, ...	441	12·00	120·00
Total . .	6,913½	1,234·00	5,028·00

The above-named ships, with the exception of the "Amberwitch," were sailing vessels, the Government of India being possessed of steamers (formerly belonging to the India navy) suitable for towing the sailing vessels during the laying of the cable. Each ship was provided with three iron tanks, a small engine, and a Gwynne's pump for filling and emptying the tanks. Paying-out machinery, consisting of a drum and breaks with the usual stern and leading sheaves, was also fitted. These appliances were similar to those employed on previous occasions, and did not embrace any new, or noteworthy feature.

The "Amberwitch," a screw steamer of 441 tons burden and 70 horse-power, was purchased for permanent service on the line, for repairing the cable in case of need, and for carrying stores and changing the staff between the stations. She was fitted with iron tanks for receiving the cable, with paying-out machinery, with an engine and machinery for raising the cable, and with an ample stock of testing apparatus, buoys, chains, grapnels, and all other requirements for repairing submarine cables. The ships were furnished with testing apparatus, and tests were regularly taken on the voyage out, by competent electricians. They arrived in Bombay in the following order:—

Names of Ships.	Electrician in charge.	Date of Arrival.
Marian Moore, ...	Mr. E. Donovan, ...	21st December, 1863.
Kirkham, ...	Mr. E. D. Walker, ...	13th January, 1864.
Tweed, ...	Mr. T. B. Mosely, ...	5th February, 1864.
Assaye, ...	Mr. J. E. Woods, ...	10th February, 1864.
Cospatrick, ...	Mr. P. Crookes, ...	15th April, 1864.

The "Assaye" met with bad weather, and it was necessary to lighten her by emptying the tanks. It is satisfactory to record that, although the tanks in one ship were thus emptied for eleven weeks during the voyage out, not the slightest elevation of temperature occurred, owing to the portection from oxidation afforded by the outer bituminous covering. In the case of the Malta and Alexandria cable, it was stated by Mr. H. C. Forde, M. Inst., C.E., that the dangerous increase of temperature which took place, when a cable without such protection was left uncovered by water, was the source of considerable anxiety.

During the passage of the cable to Bombay, constant tests were made on board the several vessels, and some interesting records were taken of the currents produced by the action of the earth's magnetism on the coils of cable, at each roll of the vessel. These were most evident in the higher latitudes, became invisible at the equator, and were in the reverse direction in the southern hemisphere. In rough weather, they were sufficiently powerful to interfere seriously with the measurements of the conductivity of the copper wire; but this evil might be at any time obviated, by coiling one half the cable in a reverse direction to the other half.

Sufficient cable for the section between Gwadur and Mussendom having arrived at Bombay in the "Marian Moore" and the "Kirkham," these vessels were towed to Gwadur by the "Zenobia" and "Semiramis," two powerful paddle-wheel steamers of the Bombay marine, commanded respectively by Lieuts. Carpendale and Crockett, formerly of the Indian navy. On the 3rd February the end of the cable was landed from the "Kirkham," with the aid of the gun-boat "Clyde" (Lieut. Hewett), and of the paddle-box boats of the "Zenobia." At 8·0 p.m. on the following day the Author commenced laying the cable from the "Kirkham," in tow of the "Zenobia," towards Mussendom; the screw steamer "Coromannel," commanded by Lieut. Carew, with Colonel Stewart on board, piloting the course. On the morning of the 6th, having laid all the cable from the "Kirkham," she was anchored in lat. 25° 19′, long. 59° 9′, Ras Mundanny bearing N.W. ¾ W. In the afternoon the "Marian Moore," in tow of the "Semiramis," was brought to anchor, in a convenient position for passing over the end of the cable for splicing, and for transferring the stores from the "Kirkham." On the following day, the laying of the cable was commenced at 4·0 p.m. from the "Marian Moore," the "Kirkham" being sent back to Bombay for discharge in tow of the "Semiramis."

On the morning of the 8th the ships anchored off Ras Jask until the evening, in order to make the Arabian coast the next morning, by daylight. The following day, at noon, the "Marian Moore" come to anchor in Malcolm's Inlet, a quarter of a mile from the landing place. The end of the cable was not landed until the 13th, a short land line having been constructed, in the mean time, to a temporary station on the other side of the peninsula. Mr. Newall's cones and rings were employed in each vessel, and everything worked well and smoothly during the laying of the cable, no incident having occurred worthy of special remark.

Except in the cases of an unsuccessful attempt to connect Cagliari with the coast of Africa, in 1855, and of a cable which was lost, between Newfoundland and Prince Edward's Island, in the same year, submarine cables have hitherto been laid from steam vessels. But, although it is convenient to have steam power immediately under control, on board the ship in which the cable is coiled, the Author considers that in some cases, such as the work now described, where the cable is to be laid in a sea rarely subject to disturbance during the seasons for submergence, and where the depth of water is not great, sailing ships, towed by steam vessels, may be employed with safety, and it will be found that the economy in so doing, when the cable has to be conveyed a great distance to its destination, is very considerable. In this instance no difficulty of any kind was experienced. The steamer towed the cable-ship with two hawsers, and the ships were in constant communication, by a complete system of signalling. During the day, an apparatus, consisting of a lever carrying a white disc in front of a black board, was placed at the stern of the steamer, and on the forecastle of the cable-ship. By night, a signal lantern, with an obscuring disc, was used. Telegraph signallers on board each vessel were always on duty, using the dot and dash telegraphic alphabet with the apparatus. By this means, every requisite message was rapidly sent to the towing steamer, and the instructions conveyed were so promptly despatched and acted upon, that no inconvenience whatever was felt from the separation of the vessels.

The electrical observations made on board ship during the paying-out of the cable, were numerous, and required thirty-four columns of figures at each set of measurements. They comprised a test for conductivity and insulation, and the power of communication with the main land for five minutes, every quarter of an hour. The admirable marine galvanometer of Professor William Thomson, F.R.S., was used. This consisted of a doubly

suspended needle and coil, with a small mirror and reflecting apparatus. The instrument was enclosed in a massive case of wrought iron, to reduce the effect of the earth's magnetism.

After the completion of the Gwadur and Mussendom section, some delay arose, owing to the other ships not having arrived. The time was occupied in establishing a station upon an island in Elphinstone Inlet, and in coaling the steamers at Bassadore and Muscat, where supplies of coal had been provided by the Government of Bombay, to meet the requirements of the expedition.

The "Tweed" and "Assaye" arrived in Elphinstone Inlet on the 12th and 13th March respectively; and on the afternoon of the 18th of the same month, the laying of the cable towards Bushire was commenced. Nothing that requires special remark occurred during the laying of this section, nor in the completion of the other portions of the line. The distance run, the length of cable laid, and the depths of the several sections, are given in the following table:—

Section.	Distance Run in Nautical Miles.	Cable Laid in Nautical Miles.	Mean Depth in Fathoms.	Greatest Depth in Fathoms.	Date of Completion.
Gwadur-Mussendom, .	345·50	357·34	47	122	Feb. 14, 1864.
Mussendom-Bushire, .	379·25	392·65	35	58	March 25, 1864.
Bushire-Fao, ...	149·00	152·20	20	26	April 5, 1864.
Gwadur-Kurrachee, .	241·00	246·00	20	64	May 15, 1864.
Total . .	1,114·75	1,148·19	...	...	...

An additional length of 18 miles of cable was added to the Gwadur-Kurrachee section, to bring the line to Minora point near Kurrachee, in place of Cape Möaree (the original landing place), making the length of that section 264 miles, and the total length of cable laid 1,176 miles.

The line in the Gulf and across its entrance, is laid upon an exceedingly regular bottom; upon a portion of the Mekran coast, and especially between Gwadur and Kurrachee, the bottom is by no means so good, being in some places rocky and very irregular. To have laid the line more to the south, would have imperilled the successful accomplishment of repairs, in case of need hereafter; but the cable is no doubt subject to risk upon this section, and has already required repair in shallow water, from chafing on the rocks during the S.W. monsoon in the year 1864.

The temperature of the sea, at the upper end of the Persian Gulf, was, when the cable was laid, 21° centigrade at the surface, and 17° at the bottom; at the entrance to the Gulf, it was 23° at the surface, and 21·5° at the bottom; and near Kurrachee, 26° at the surface, and 24·2° at the bottom.

The following are the insulation tests taken after immersion :—

Section.	Temperature at the Bottom.	Resistance per Nautical Mile.	
		Siemens' Units.	British Absolute Units.
Gwadur-Mussendom, . . .	22° centigrade	358 millions	342 millions
Mussendom-Bushire, . . .	21 „	390 „	373 „
Bushire-Fao, ...	17 „	601 „	575 „
Gwadur-Kurrachee, . . .	24 „	280 „	268 „

It will be observed that, there is apparently a great difference between the insulation of the several sections. By reducing the resistances, however, to the same temperature, they will be found to be remarkably uniform. Thus the comparative resistances at 24° centigrade, the temperature of the Gwadur-Kurrachee section, and also that at which the tests were taken during the manufacture of the core, are—

Section.	Resistance per Nautical Mile.	
	Siemens' Units.	British Absolute Units.
Gwadur-Mussendom, . . .	286 millions	274 millions
Mussendom-Bushire, . . .	279 „	267 „
Bushire-Fao, ...	276 „	264 „
Gwadur-Kurrachee, . . .	280 „	268 „

If the cable, offering a mean resistance of 280 millions of Siemens' units per nautical mile, had been laid in sufficiently deep water to reach the unvarying temperature of 39·5° Fahrenheit, or about 4° centigrade, which is met with at a depth of 1,500 fathoms, the resistance would have increased, by the difference of temperature, to about 2,600 millions of units per nautical mile, with the additional increase due to pressure, which is about 16 per cent., for every 200 fathoms.

From the date of the completion of the submarine line in April 1864, it has been regularly worked by an efficient staff of station superintendents and signallers, selected from the service of the telegraph companies in this country. Mr. Walton, who had charge previously of the Mekran Coast Telegraph, is the chief superintendent. Instruments of the most modern construction are employed at each station, supplied by Messrs. Siemens and Halske, who also provided the iron posts and insulators, used over part of the Turkish and Persian land lines.

It was expected that the Turkish land line, between Bagdad and the head of the Gulf, would have been completed simultaneously with the submersion of the Persian Gulf cable. In this, however, much disappointment was experienced, notwithstanding the indefatigable exertions of Colonel Kemball, C.B., H.M.'s Resident at Bagdad. The line was completed with the aid of Mr. T. H. Greener, southwards, from Bagdad to Hillah, and thence to Diwanyeh, and northwards, from Fao to Korneh, where the Tigris and Euphrates meeting, form the Shat-el-Arab: but the Montefic tribe of Arabs being in revolt against the Turkish Government, the completion of the line was delayed until the commencement of the year 1865. It was not until the end of February, that arrangements had been so far organized, as to allow of the line to India being opened for the transmission of public messages, when a telegram was received in London from Kurrachee, in eight hours and a half. This was speedily followed by numerous commercial messages to and fro; and the line is now in daily operation, carrying a large traffic between India and Europe.

In the working of the Turkish line, there is, however, much room for improvement, which it is hoped the importance of the traffic will induce. Before long, the opening of the Persian line of telegraph from Teheran to Ispahan, Shiraz, and Bushire, with the connecting line from Bagdad, by Khanakain, to Teheran, will afford an additional route by which the Persian Gulf cable may be reached, passing through Russia by way of Tiflis and Erivan, and the competition of the two lines will no doubt materially improve the service.

These extensive lines have been finished under the superintendence of Major J. U. Champain, R.E., assisted by Lieutenants Pearson and St. John, R.E., and a few selected non-commissioned officers and men. The energy and perseverance with which this arduous duty has been performed, can be best appreciated by those who have worked in an Oriental country, with all

the difficulties of absence of land carriage and labor, coupled with every form of official apathy and obstructiveness.

The extension of the telegraph to Australia must speedily follow the successful establishment of electrical communication between India and Europe. At present, the Indian telegraphs are constructed as far to the eastward as Rangoon; the distance thence to Singapore is about the same as that of the Persian Gulf line, and a route with a favorable bottom can be selected for a cable. Between Penang and Singapore it would be desirable to lay a heavier cable than in the northern portions of the line.

The feasibility of establishing a land line down the Malay Peninsula demands consideration, before determining upon the adoption of the sea route. There are no insurmountable physical difficulties, as regards either the country or its inhabitants, to prevent the erection and maintenance of a land line. There are, however, no roads, except mere bridle-paths, to the south of Tavoy, and a large expense must be incurred in clearing the jungle.

The cost of a submarine cable in Europe compared with a land line, is very great; but the cost of a land line in uncivilized countries, without facilities for the conveyance of stores and workmen, is considerably increased; while the cost of maintenance, and the chances of interruption and delay, in re-establishing communication, are also greater. The regularity of the working of a properly-constructed cable would, in the Author's opinion, soon compensate for the additional outlay involved in the adoption of the sea route, by which also the communication could be more speedily effected.

Between Singapore and Hong Kong, a cable can be readily carried in shallow water, touching at Saigon; or the connection with China may be made by crossing the peninsula with a land line at Mergui, and carrying a cable across the Gulf of Siam. A further portion of the route might be carried by land, by way of Bangkok, and Cochin China; but the Author is of opinion that although a branch, or a loop line, might be taken by land in this direction, the main line, upon which the regularity of the Chinese traffic would depend, should be submarine.

It has been proposed to take a land line of telegraph from Rangoon, through Burmah and Western China; and the arguments urged in favor of this route by its projector, Captain Sprye, are very strong. The Russian Government is also gradually extending the telegraphs to the Chinese

frontier, with the intention of ultimately connecting Pekin with the Russian system.

To discuss the relative geographical and commercial features of these projects would exceed the limits of this Paper; but the Author considers, that at present the best, most reliable, and most speedy plan for connecting China to India by telegraph, is by a submarine cable.

Proceeding southwards from Singapore towards Australia, the first section, from Singapore to Banca Island and Java, can be taken in shallow water. A cable laid in 1858 from Singapore to Batavia failed soon after being laid; but the cable was a very light one, and unsuited to the bottom. By selecting the route to be followed, and laying a properly-constructed cable, there would be no difficulty in maintaining permanent communication between these points. A land line of telegraph has already been constructed by the Dutch Government, throughout Java, and a cable may be taken from the south-eastern extremity of that island to Timor, terminating at a station to be established at Coupang. From Timor to the north coast of Australia, a submarine line can also be laid in shallow water, with the exception of a short distance to the south of this island, where the depth is not known, no positive soundings having been yet taken. The telegraph is rapidly extending northwards, from Brisbane towards the Gulf of Carpentaria, and the whole of the intermediate country is being quickly occupied by settlers.

The Author cannot conclude without expressing his deep regret, that Colonel Stewart did not survive to witness the completion of his labors, the opening of the Indo-European line, to the accomplishment of which he so largely contributed by his energy and perseverance. By his death the country has lost an accomplished and fearless officer, unsurpassed in zealous devotion to his duties, and rarely equalled in administrative capacity.

No. CXLIV.

ECONOMY OF STEAM POWER IN INDIA.

Notes on the Economy of the Steam Flour Mill, lately erected at the Commissariat Bakery, at Bareilly. By CAPT. C. S. THOMASON, R.E.

BAZAR wheat, 230 maunds 9 seers 9 chittacks (230·24 maunds), at the rate of 13 seers 11 chittacks per rupee, is purchased for Rs. 663·516.

The above wheat is first passed through the winnowing machine, and the out-turn is found to be—

	mds.	s.	c.	maunds.
1st class wheat, ...	192	10	0	(192·25)
2nd " "	29	37	4	(29·931)
Foreign grain and waste, ...	8	2	5	

After passing through the mill (excepting the foreign grain, which is valued unground) the out-turn is classified and valued as follows, at bazar rates:—

From	Out-turn.				Remarks.
	Classification.	Quantity in maunds.	Rate per maund.	Value.	
			RS.	RS.	
1st class wheat, 192 mds. 10 srs.,	Flour, ..	64·734	5·614	363·42	Actually ground from Oct. 1st to Oct. 8th, in 62·25 hours.
	Soojee, ..	65·635	8 000	525·08	
	Atta, ..	30·640	3 265	100 04	
	Bran, ..	31 241	1·684	52·61	
		192·250			
2nd class wheat, 29 mds. 37 srs. 4 cks., ...	Atta, ..	29·931	3·265	97·72	Cost of grinding assumed same as for 1st class wheat.
Foreign grain,	Foreign grain,	8·056	3·000	24·17	Rate probably too high.
Total value of out-turn from 230 maunds 9 seers 9 chittacks bazar wheat, Rupees				1,163·04	

In obtaining the above result, the following machinery was employed :—

1*st.* Winnowing machine (for $2\frac{1}{2}$ days), cost Rs. 300 in Bareilly—estimated to last 5 years—wear and tear, Rs. ·17 per day.

2*nd.* Ransome's 36 inch Flour Mill and Dresser, cost Rs. 1,500 in Bareilly—to last 7 years—wear and tear, at Rs. ·59 per day.

3*rd.* Clayton and Shuttleworth's 10 horse-power Traction Engine, cost Rs. 7,400 in Bareilly—3 horse-power is used and estimated at cost of Rs. 2,220; and engine is estimated to last 10 years—wear and tear on 3 horse-power, at Rs. ·61 per day.

The total amount of capital represented is therefore Rs. 4,020; interest on which is Rs. ·58 per day.

The difference between value of wheat purchased (Rs. 663·52) and out-turn (Rs. 1,163·04) is Rs. 499·52; to obtain which the following expenditure is incurred :—

Particulars.		Rs.	Remarks.
	Rs.		
Winnowing machine, labor of, 230 24 maunds, at Rs. 0-8 per 100 maunds, ...	1·15		2 men and a boy can winnow 100 maunds per day.
Wear and tear of winnowing machine, $2\frac{1}{2}$ days, at Rs. ·17, ...	·43	1 58	
Grinding and dressing, 192 25 maunds 1st class wheat, in 6 25 days.			
Engine wages, at Rs 20 per mensem, ..	4·17		*Vide* journal of actual expenditure from Oct. 1st to 8th, actually paid.
128 maunds fuel, at Rs. 20 per 100 maunds, ...	25·60		
Mill wages, 2 coolies, Rs. 5 per mensem, for 6 25 days, ...	2·08		Estimated.
Wear and tear 3 horse-power engine for 6·25 days, at Rs. ·61 per day, ...	3 81		
Ditto of mill, at Rs ·59 per day, ..	3 69		Do.
Oil, grease and waste, $6\frac{1}{4}$ days, ...	6 25		Founded on experience.
Repairs of machinery, $6\frac{1}{4}$ days, at Rs. 1 per day, ...	6·25		Estimated.
Interest on capital, engine and mill, $6\frac{1}{4}$ days, at Rs. 5 per cent. per annum, ...	3·18		Do.
Establishment, supervision, accounts, weighmen, &c., $6\frac{1}{4}$ days, at Rs. 4 per day, ..	25·00	80 03	Do.
Grinding 29 931 maunds of 2nd class wheat, at same rate, ...	12 46	12·46	Do.
Cleaning soojee from 1st class wheat, $6\frac{1}{4}$ days, at Rs. 1, ...	6·25	6 25	Do.
Total cost of obtaining out-turn,	..	100 32	

Leaving a profit of Rs. 399·20 in $6\frac{1}{4}$ days, which recovers the whole outlay in 63 days.

Notes on preceding calculations.—The out-turn of the mill and engine (3 horse-power) may be taken at 30 maunds a day.

The working cost of engine and mill is about Rs. 13 per day.

If the Commissariat were to work for themselves, their profits would be much greater even than here shown; for the following reason, viz., 1*st*, They would require at least two mills, which might be worked by one 6 horse-power horizontal stationary engine, cost of which per horse-power would be less than here shown; the engine wages would remain the same, as also would the item of Rs. 25 per day for establishment, almost the heaviest item in the costs.

2*nd*. It is more than probable that the heaviest item of all (Rs. 25·60 for fuel) might be almost, if not entirely, saved, by the Commissariat burning the refuse of their cattle-yards, an experiment still to be tried here, but a measure frequently resorted to in England.

The winnowing machine was purchased in Calcutta, and its cost is very much in excess (perhaps double) of what it would have cost if purchased in England and imported here. It ought to be worked by the same engine that turns the mill.

The cost of the building has not been included in the calculation as there was one already available in the Commissariat yard: if required, one might certainly be built at a cost of Rs. 2,500.

The building should be two-storied, and if a lift to the upper story, worked by steam, were attached, it would prove economical. An English weighing machine would save labor, and might be attached at a small cost. One for weighing up to 2 tons cost me £20 fixed in Scotland; it would probably cost Rs. 270 here.

The Commissariat should use none but the best neat's foot oil, which they might make for themselves; it would be not only a saving in first cost, but would also save much wear and tear due to the wretched castor oil at present procurable in Bareilly.

The soojee cleaning, an expensive item as done by hand, if considered necessary, might I think without very great difficulty be done by machine worked by the engine.

It might perhaps be as well to lift the mill a little higher off the ground and have the out-turn shot direct into bags.

BAREILLY,
December 19*th*, 1866.

C. S. T.

No. CXLV.

CARROLL'S PATENT CANAL MODULE.

It has long been a desideratum amongst Canal Engineers in India, to have some practicable means of measuring the quantity of water actually delivered through the irrigation outlets of the distributary channels, so that the present objectionable and expensive system of charging according to area irrigated may be done away with. The conditions required for such a contrivance are briefly:—

That there must be a constant and uniform discharge through the outlet (Kolaba) under the varying heads of pressure that practically occur in a rajbuha or distributary water-course. That the contrivance for securing such a discharge must be inexpensive (or it would be out of the reach of the agriculturist), simple (or it would be constantly getting out of order), not easily tampered with (or it would lead to fraud), and not liable to be choked by silt.

Several contrivances have been proposed by ingenious inventors at different times, but none of them have been practically successful. The following, however, which has been invented and patented by Lieutenant Carroll, R.E., so far as it has hitherto been tried on the Ganges Canal, bids fair to answer the purpose effectually; and like many other inventions of equal or greater importance, its construction and method of working are exceedingly simple. Unhappily the clever inventor has been compelled by ill health to quit the country, and to leave to others the carrying out of his idea.—[Ed.]

Description of the Module.

To the mouth of the kolaba a valve is attached of the form and dimensions shown in the Plate, and which may be made of brass or iron.

Its mode of action is very simple. When the plate which hangs in

front of the tube is down, the quadrant which is attached to it, is at its highest point, and it will be seen that a free water-way exist through the tube and between its under lip and the plate in front. If the plate be raised, the quadrant sinks into the tube, and reduces the water-way in proportion to the angle the plate is raised through.

Now, if it be desired to obtain an equal discharge while the head of water in the canal varies from 3 feet down to 1 foot, the plate is weighted so that the force of the issuing stream at a 1 foot head shall be just unable to move the plate outwards. As the head rises above this, the velocity of the stream becomes greater and drives out the plate, thus reducing the water-way till, at a 3 feet head, the plate will remain at a very high angle, and the quadrant will close a great part of the water-way of the tube. The curve of the plate is so adjusted that it shall rest at such an angle as to give the same discharge as at a 1 foot head; when this is done, it is found that at all intermediate heads the discharge remains almost the same. Experiment gives 1 per cent. as the ordinary deviation from exact equality. This module can be equally well applied to regulate under lower heads such as from 1 foot to 3 inches, but requires lighter weights and some other simple adjustments.

The merits claimed for this module are simplicity, cheapness, non-liability to derangement or choking, and the ease with which it can be protected from injury by enclosing it in a small masonry or iron chamber.

The following table shows the result of a series of experiments made with the Module, as lately erected at Tooghulpore on the Ganges Canal, to ascertain the actual deviation from the normal discharge under varying heads of pressure.

The mode of measuring was as follows :—

The Reservoir connected with the Canal was filled and allowed then to empty itself through the module, which discharged into the measuring tank. The outlets from this consisted of two sluices cut in a sâl wood plank: one below the other, hence the different heads shown on the Abstract (while the water level remained the same), according as the upper or lower one was used.

As the water in the Reservoir fell slowly, the head in the measuring tank was recorded at each decimal of a foot of that fall, and the table here given merely records the extreme of its variation. These variations being very small, the level of the water in this tank is noted as ·1 foot above sill

Abstract of Experiments made on a Module at Tooghulpore, Ganges Canal, in January and February, 1867.

Variation of head in canal over sill of kolabah.	Variation of head over centre of outlet from measuring tank.	Variations of last number or numbers proportional to extreme discharges.	Mean of the variations of heads or number proportional to mean discharge.	Greatest deviation from mean discharge, measured as a percentage of mean discharge.	Angular traverse of the valve plate between extreme heads, measured from the	Adjustments. Height on valve plate.		Adjustments. Level of water surface in measuring tank.	Remarks.
ft.	ft.	ft.	ft.			lbs.	oz		
3·0 to 1·1	·465 to ·450	·6819 to ·6708	·6768	·6819, or 0·7 p. c.	56° to 27°	7	2	·1 ft. above sill of module	Mean discharge = ·688 c. ft. per second
3·1 to 1·1	2·205 to 2·040	1·485 to 1·428	1·443	1·428, „ 1·0 „	57° to 27°	7	2	·1 ft ditto,	
3·0 to 1·1	2·145 to 2·010	1·465 to 1·418	1·438	1·465, „ 1·5 „	57° to 27°30	7	2	·1 ft. ditto,	
2·0 to 0·9	·620 to ·560	·7874 to ·7483	·7629	·7348, „ 1·8 „	62° to 34°30′	3	11	·1 ft. ditto,	Mean discharge = ·5017 c.ft. per second.
2·0 to 0·9	·625 to ·555	·7906 to ·7450	·7594	·7450, „ 1·8 „	62° to 34°30′	3	11	·1 ft. ditto,	
4·5 to 1·3	·572 to ·527	·7563 to ·7259	·7363	·7563, „ 2·7 „	60° to 26°	8	5	·1 ft. ditto,	Calculated discharge from (·7363)² as head over centre of rectangular orifice ·6305 ft. × ·335 ft.
4·0 to 1·3	·547 to ·527	·7396 to ·7259	·7340	·7259, „ 1·0 „	56° to 26°	8	5	·1 ft. ditto,	
4·0 to 1·3	·597 to ·617	·7727 to ·7855	·7737	·7855, „ 1·5 „	56° to 26°	8	5	·1 ft. ditto,	

In these last experiments the height of the mouth of the module is reduced a little.

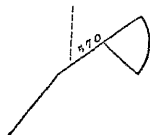
The above are selected from more than 60 experiments made on the valve with different heights, and with its adjustable plate set at different angles; when results as good as these had been obtained, the experiment was repeated four or five times till it was certain that accident had nothing to do with the result. It is necessary to state this to show that these results are not such as might by chance be obtained with a bad valve out of so many experiments.

This table gives only the extreme heads in each experiment; but in the observations themselves, all the heads at each decimal of a foot were entered, and the corresponding heads in the measuring tank. The means given are the means of all of these, and not of the extreme only.

of module, which is about the mean level, and it is desirable that this should be the ordinary level of the run off from a valve in practice.

The angles given are those of the upper part of the valve plate with the vertical thus—

By observing this angle a new valve can be weighted to the proper extent.

It will be observed that the only alterations required to adapt the valve to different ranges of variation of heads, is the alteration of the weights and orifice. The first three experiments are on the most useful form; the cast-iron valve to give 1 cubic foot a second has been designed from this form.

No. CXLVI.

ARTIFICIAL HYDRAULIC LIME.

Description of method used in preparing Hydraulic Lime in Sind, and particularly at Kurrachee. By W. H. Price, Esq., M. Inst., C.E., *Superintendent Kurrachee Harbor Works.*

The following memorandum is the result of experience in the manufacture and use of artificial hydraulic lime, both in fresh and sea water, during nearly nine years, in the province of Sind; and, as such, may possibly be useful to members of the profession who may have hydraulic works to carry out, at places where natural hydraulic limestone, or reliable puzzuolanas (either natural or artificial) are not procurable, or are at a distance from a market where European cements of suitable quality can be had at reasonable rates.

The process in question was originated I believe by M. Vicat, as described in his "Treatise on Calcareous Mortars and Cements,"* and in the Treatise of Major Gillmore, U. S. Engineers,† as well as in other works.

The method presented therefore no novelty in principle, but was untried in this province, so that it was not without anxiety that I entered on its use for important hydraulic works.

* Treatise on "Calcareous Mortars and Cements." By L. J. Vicat, Engineer in Chief of Bridges and Roads, &c., &c., translated by Captain J. T. Smith, Madras Engineers, F.R.S., &c., &c. London, John Weale, 1837.

† "Practical Treatise on Limes, Hydraulic Cements and Mortars" By Q. A. Gillmore, A.M., Brigadier General of U. S. Volunteers, and Major U. S. Corps of Engineers. New York, D. Van Nostrand, 1863.

My first trial of the material was in 1858, in the building of a regulating bridge across the "Narra supply channel," opening from the Indus, at Roree; and my experience of the lime in that work led me afterwards to employ it on the Kurrachee Harbor Works, commenced in 1860. Here, at first, I used the lime with caution, fearing that though it had proved good in fresh water, it might not prove equally strong or durable in salt; but finding it to answer well in the latter also, the lime was used largely by me; and during my absence in Europe, by Lieut. Merewether, R.E.

Since February 1862, about 50,000 cubic feet, equal to about 800 tons in weight, of the lime, have been used on the Harbor Works, and in no case has it been found to fail.

The material was especially found most valuable in concrete foundations for considerable lengths of wharf walls, in soft mud and quicksand, thus superseding the use of timber platforms or piling, or other expensive methods.

The process of manufacture described in the annexed memorandum is that employed on the Harbor Works since the mortar mills driven by steam power were brought into use; previous to which, the mixture of the lime and clay was made in the ordinary country mill, consisting of a stone roller running in a circular trough, and worked by bullocks. The latter method was also used at Roree, and is still I believe employed on the works of the Sukkur and Shadadpoor Canal, now in progress in Upper Sind. The mill worked by steam power is of course more effective, and at Kurrachee, at least, has been found to do the work more cheaply than the country mill.

The kiln, of which a drawing is appended, is one of the "alternating" kind used on the Harbor Works; it differs little from the kiln suggested in M. Vicat's work, pages 159-160.

At Roree, and at first on the Harbor Works, the ordinary small single country kiln was used, but the three chamber "alternating" kiln is far more economical of fuel, and burns the lime more uniformly.

The appended table, showing the cost of manufacture at Kurrachee (amounting to ten annas = 1*s.* 3*d.* per cubic foot) may prove useful. The "per centage" column will afford the means of framing an estimate in other localities, according to the rates of the different items of labor or materials there prevailing.

This lime follows the law of hydraulic limes in general, in admitting

but a small proportion of sand (as compared with rich or fat limes) in the composition of the mortar.

The proportions used on the Harbor Works have usually been:—

For mortar, for concrete,* and footings,	1 lime to 3 sand, parts by measure.
For superstructure, ...	1 „ to 2 „ „

Though fresh water is indispensable in the mixing of the rich lime and clay, before reburning, yet in the making of the *mortar*, salt water has been generally used on the Harbor Works, and has been found to answer as well as (if not better than) fresh water.

Attention has latterly been turned to the comparison of Portland cement (imported from England) with the hydraulic lime, and Lieut. Merewether, R.E., has undertaken a series of experiments on the two materials with the view to determine which ought to be recommended for the preparation of blocks of artificial stone, for the projected Manora break-water. There is no doubt that either material will make good work, so that the question resolves itself mainly into one of comparative cost.

The lime is (as might be supposed), bulk for bulk, very much cheaper than the cement; but the latter takes the larger proportion of sand, and the main object of the experiments now in hand is to determine up to what limit the admixture of sand with the cement may be carried, while producing a mortar equal in strength and durability to that made with the hydraulic lime.

To determine this satisfactorily will require some time and numerous trials of different kinds. An important element in the question is of course the lowest rate at which Portland cement of suitable quality can be supplied at Kurrachee. The sample from which the experiments are being made, sold at about four times the cost of the hydraulic lime per cubic foot. At such a rate there could be no inducement to adopt the cement; but judging from English prices, there is reason to believe a steady demand here would induce a supply at a much lower rate than the above. This point, however, remains to be exactly determined.

In connection with the subject of hydraulic cements, it might be suggested as interesting to the profession, that some officers should give their experience in the use of puzzuolanas, natural or artificial; and among the latter particularly of "soorkhee," or pounded brick, a material so much em-

* The concrete is made by mixing with the mortar twice its bulk of stone, broken to pass through a 2-inch ring.

ployed in the North West Provinces, and other parts of India, in the composition of mortar for hydraulic works.

Experiments on the latter material made in Sind, caused me to abandon the idea of its use, as the mixture of pounded brick with rich lime, formed a cement, either not at all, or but feebly, hydraulic.

The use of (even the best natural) puzzuolanas with rich limes, would seem at best doubtful, particularly for sea works, serious failures having been reported by eminent French Engineers. *See* Gillmore on Limes, &c., pages 99 to 109, Arts. 150 to 162. There seems, indeed, reason to believe that Portland cement is coming much into use on the Continent as well as in England, in supersession of puzzuolana, especially for sea works.

Process of manufacture of artificial hydraulic lime on the Kurrachee Harbor Works.—Ordinary rich (fat) lime slaked to powder, is mixed with clay, in the proportions of 5½ parts, by measure, of lime, to 1 part of clay.

The rich lime used on the Harbor Works has been generally made from the hard crystalline limestone procured from the "Gizree" hills, near Kurrachee.*

The clay is procured *in situ* from the bed of the Lyaree river, and is of the description that might be used for bricks or coarse pottery.

The mixture of the lime and clay is made in a mortar pan worked by steam power,† a sufficient quantity of water being added to bring it to the consistency of moderately stiff mortar. The amalgamation should be very thoroughly effected, as upon this greatly depends the quality of the lime.‡

The mixture is then made by hand into balls of about the size of a large orange, which are laid out on the ground in the sun to dry. When thoroughly dried, which takes from two to six days according to the weather, the balls are burned in a kiln; or if the lime is not likely to be soon required, they are stored in a shed. It is most important that the balls should be thoroughly dried before burning.

* Shell lime would probably be found a tolerable substitute where limestone is not easily available.

† At the Roree regulating bridge, the mixture was made by a stone roller, running in a circular trough of brickwork, and worked by bullocks.

‡ If the mixture is propely made, the balls after drying should show a uniform gray color when broken, the white specks of lime not being easily distinguishable.

The method of burning the lime is as follows:—

The kiln used (*vide* drawing) is constructed on the principle of "alternately foies" (suggested by M. Vicat for the burning of hydraulic lime), the base being in three compartments or chambers, and the chimney in one, common to the three chambers.

Each chamber has an opening for firing, to which a sliding door of iron is attached for regulating the draught.

The lower portion of the charge is formed of limestone hand rubble, laid in the form of a vault, 8 to 10 inches thick, over each chamber.

Above the vaults the kiln is to be filled in with the balls, pieces of firewood being placed vertically at intervals of about 2 feet, to facilitate the draught.

The top of the kiln is left open, but the openings for drawing the lime are closed with sun-dried brick, plastered over.

The chambers are lighted in rotation, each for 20 hours at a time, until the burning has continued for the usual period of 120 hours, being the time required if babool (*Acacia*) wood be used for firing; if jhow (*Tamarisk*) wood be used, 144 hours are required, to be divided proportionately.

The doors of the chambers not in action are closed, the chinks being plastered over with clay.

After the burning, one day is allowed for cooling the kiln, after which the doors may be opened and the lime drawn.

The kiln requires for burning from 400 to 450 maunds (maund equal 82 lbs.) of firewood, if jhow, be used; if babool, 360 to 400 maunds.

The return is from 700 to 730 cubic feet of hydraulic lime, and 160 to 180 maunds (maund equal 2¼ cubic feet, measured after slaking) of rich lime.

The quantity of limestone required for the vaulting is from 260 to 290 cubic feet, measured as stacked in heap.

After the burning, the hydraulic lime may be slaked for use in the same manner as ordinary lime. If kept a little time, however, the balls fall to powder, more or less from exposure to the air, but the lime will keep good in this way for some weeks or even months. It is necessary, however, to store the lime under shelter in a closed shed.

The lime prepared under the foregoing process, set under water in from 24 to 48 hours, and appears in every way to fulfil the conditions of an eminently hydraulic lime, as defined by M. Vicat.

Details of cost of manufacture of one kiln yielding about 700 cubic feet :—

NOTE—The lime measures about the same in cubic content whether in balls or after having fallen into powder.

Particulars.	Description.	No.	Rate.	Per	Amount.	Total	Per centage.
					R. A. P.	R. A. P.	
MATERIALS.							
Rich lime, - - -	Maunds, Cubic ft.	362 815	1 0 0	mds. 2½	144 12 9		
Limestone for base of charge, - - -	Cubic ft.	290	6 4 0	c. ft. 100	18 2 0		
Water (fresh) for slaking lime, obtained from base of charge,	Gallons,	900	0 5 0	galls. 100	2 13 0		
Labor for slaking and measuring lime obtained from base,	Laborers, " Boys, "	21 1 6 4	0 6 0 0 7 0 0 3 6 0 3 0	diem, " " "	7 14 0 0 7 0 1 5 0 0 12 0		
					176 1 9		
Deduct value of rich lime obtained from base of charge,- -	Maunds,	170	1 0 0	mds. 2½	68 0 0	108 1 9	24·70
Clay, - - - -	Cubic ft.	148	6 0 0	c. ft. 100	8 14 0	8 14 0	2·03
Water (fresh) for mixing lime and clay, -	Gallons,	1,600	0 5 0	galls. 100	5 0 0	5 0 0	1·14
Firewood (babool),-	Maunds, lbs.,	380 31160	1 0 0	mds. 2½	152 0 0	152 0 0	34·74
LABOR, MIXING LIME AND CLAY.							
Manual labor, -	Laborer, " Boys,	10 32 7	0 7 0 0 6 0 0 3 0	diem, " "	4 6 0 12 0 0 1 5 0	17 11 0	4·05
Machinery charges for mixing by steam mortar mill, -	..	..	..	..	40 11 0	40 11 0	9·30
Dividing the paste into balls,- - - -	Women,	39½	0 4 0	diem,	9 14 0	9 14 0	2·26
Carried over, -	..	..	..	..	..	342 3 9	78·22

Particulars.	Description.	No.	Rate.	Per	Amount.	Total.	Per centage.
					R. A. P.	R. A. P.	
Brought over, -	..	..	..	..	..	342 3 9	78·22
Loading kiln, -	Laborers,	3	0 7 0	diem,	1 5 0		
	„	24	0 6 0	„	9 0 0		
	Women,	3	0 4 0	„	0 12 0		
	Boys,	5	0 3 6	„	1 1 6		
	„	6	0 3 0	„	1 2 0	13 4 6	3·04
Firing kiln including removal of firewood,	Laborers,	8	0 7 0	„	3 8 0		
	„	12¼	0 6 0	„	4 9 6	8 1 6	1·85
Drawing kiln and storing lime, -	Laborer,	12	0 7 0	„	5 4 0		
	„	23	0 6 0	„	8 10 0		
	Women,	1	0 4 0	„	0 4 0	14 2 0	3·23
Foreman lime burner,-	..	Days. 20	1 0 0	„	0 0 0	20 0 0	4·57
						397 11 9	90·91
Add for depreciation of, and repairs to, kiln, lime sheds, tools, and charge for service ground occupied in drying balls, - -	..	..	10 0 0	per c.	..	39 12 4	9·09
Total cost of 700 cubic feet of lime, - -	..	..	..	..	..	437 8 1	100·00
Cost of one cubic foot,	..	..	..	..	..	0 10 0	..

NOTE.—The cost of the hydraulic lime at Roree in 1858 was about 2 annas per cubic foot, but there, labor was only about one-third and firewood one-fourth Kurrachee rates; also stone clay and water were procured on the spot at nominal cost, while all these materials have to be brought from a considerable distance at Kurrachee. Such lime now costs at Roree about 3 annas 7 pies per cubic foot, or 1 rupee for 2 maunds.

W. H. P.

NOTE BY EDITOR.

The following extract is from the Thomason College Manual on Limes and Cements.

Major H. A. Brownlow, R.E., Superintendent Eastern Jumna Canal, made a

most excellent cement from the stone lime and brown alluvial clay procured near the head of his canal, following the directions given by General Pasley,* and it very well repaid the trouble and expense laid out on it.

Hydraulic cement has also been made with considerable success in Madras and at Singapore. Lieut. Morgan on the Eastern Coast Canal, six miles north of Madras, made cement of 7 measures of shell lime to 5 measures of clay, following closely Pasley's rules for mixing and burning it. If applied under water this cement hardened in 24 hours; if applied dry and water let on it in half an hour, it hardened in 8 or 10 hours. The same cement mixed with an equal quantity of soorkhee hardened in 48 hours under water, or in 12 to 24 hours if allowed half an hour before the water was let on it.

The cost of this cement was not more than 4 annas per "parah," of 4,000 cubic inches.

Captain Man, at Singapore, found he could make a similar hydraulic cement of excellent quality using 5 measures of slaked lime to 2 of fresh blue clay.

In some experiments made at Roorkee to discover the best composition for a hydraulic cement, the bricks, the day after being joined were placed at the bottom of the Ganges Canal, and exposed to a stream of nearly 3 miles an hour. The cements were made of old fat stone lime, which had been lying under a dry arch for 6 years

* General Pasley's experiments were made principally with chalk lime, and the blue alluvial clay of the river Medway, near Chatham. The result he arrived at was, that a mixture of 4 parts by weight of pure chalk, perfectly dry, with 5·5 parts, also by weight of alluvial clay, fresh from the Medway, or of 10 parts of the former with 13¾ of the latter, would produce the strongest artifical cement that could be made by any combination of these two ingredients.

The weight of the blue clay he found to be ninety pounds, and of the dry chalk powder forty pounds per cubic foot.

His method of proceeding was as follows:—The clay was weighed when fresh from the river (taken from about eighteen inches below the surface), and was never dug unless required at once; it being found that even twenty-four hours exposure to the atmosphere injured it. The chalk was not weighed until well dried and pounded, owing to its extraordinary retentiveness of moisture. The chalk was then mixed with water into a thick paste. The chalk and clay were then each separately divided into portions or lumps as nearly as possible equal, and put alternately into a pug mill of the ordinary description where they were most thoroughly and intimately mixed. The raw cement thus formed was then made up into balls of about two and a half inches in diameter, and placed in the kiln alternately with about equal layers of fuel—a layer of fuel always being at the top and bottom. The fuel used was coke, in preference to coal; and, in the small furnace or kiln used by Sir C. Pasley, three hours was found to be about the average time required for burning the cement. As the calcined cement was drawn from the bottom of the kiln, fresh cement could be put in at the top. The balls, on being raked out, could be tested by applying to them diluted hydrochloric acid. If sufficiently burned, no effervescence ensued; but if they effervesced, they were put into the top of the kiln again to be reburnt. The calcined cement balls, since they would not slake like ordinary lime were then ground to impalpable powder, and stored for use, so that they should not be exposed to the atmosphere. The average out-turn was about nine and a half measures of calcined out of ten measures of raw cement.

Where only hard limestone is to be obtained, General Pasley suggests that instead of grinding it which would be often a difficult and expensive operation, it is better to burn the limestone and slake it before mixing it with the clay.

The above proportions formed the best artificial cements; but he has also recorded as follows:— "After due investigation, we found that any given weight of well burned chalk lime, and consequently of any other pure quick lime, fresh from the kiln, combined with *twice* its own weight of blue clay, fresh from the river, will form an excellent water cement; observing, however that the quick lime, after being weighed, must be slaked with excess of water into a thinnish paste, and allowed to remain in that state about twenty-four hours before it is mixed with the clay."

since being burnt; this was slaked, mixed with 1½, 2, and 2½ times its own weight of ordinary brown clay, following Pasley's directions. The composition of 1 lime to 2 clay, was found the best, and 1 lime to 2½ clay the worst. At the same time some fresh stone lime was ground and mixed up carefully with an equal bulk of ground soorkhee; and the result of a number of experiments proved that although the mortar made of the lime and soorkhee set in the air as hard as that made of the lime and clay burnt together, yet it would in no case set when exposed to the fo ·e of the canal stream; while the cement after 14 days under water required a breaking weight of 10 lbs. per square inch to separate the bricks. Some very hard blue clay was afterwards obtained from Hurdwar, and mixed with fresh stone lime, very slightly if at all hydraulic, in the proportion of 1 lime to 2 clay, and balls were calcined, and ground as before; of this cement four prisms were made 6″ × 2½″ × 2½″, and after 26 days immersed in water were subjected to a transverse strain, the bearing being 4 inches. The average breaking weight of the prisms was 598·5 lbs.; the greatest being 675 5 This gives the value of C the constant of strength for this cement = 153·; while for prisms of Roman cement 11 days old it was only 150.

The lime used in this part of India is derived from three sources; 1, Boulder limestones found in the beds of hill torrents; 2, Marl, or earth lime, as it is usually called; 3, Kunkur lime.

The following is an analysis lately made at Roorkee of the first two varieties:—

Nature of lime.	Moisture expelled at 212°.	Organic matter and moisture	Siliceous matter and clay.	Carbonate of lime	Carbonate of magnesia	Oxide of iron and alumina.	Total.
Marl lime, ...	1·44	1·27	49·80	37 01	2·79	7·69	100
Stone lime, ...	0·40	2·43	11 18	50·43	23·73	11·83	100

The kunkur lime is similar to No. 2, both differing widely from the stone lime. All make excellent mortars for hydraulic works; the ordinary mixture with No. 1 lime being 1 part stone lime to 2 of soorkhee, or 140 lbs. lime to 400 lbs. soorkhee (if the mortar is to be used for ordinary buildings 1 lime, 1 soorkee, 1 sand may be used). With the marl lime, 1 of lime to 1 of sand, without any soorkhee, is used.—[Ed].

No. CXLVII.

IRON MILE POSTS.

Memo. on Iron Mile Posts used in the Burdwan Local Road Division, Bengal. BY LEONARD ROBERTS, ESQ., A.I.C.E., *Executive Engineer.*

THE standards are of $1\frac{1}{2}$-inch angle iron, and cross braces of $1\frac{1}{4} \times \frac{1}{4}$-inch flat bar iron.

The figure plate is of $\frac{1}{4}$-inch boiler plate, the figures are $\frac{1}{2}$-inch in width, $3\frac{1}{4}$-inches high, and are cut through the plate with a half inch drill, and then filed to shape; their outline being previously scribed from tin templates. The plan answers very well, and the figures show very distinctly when the posts are in position.

The rivets are all $\frac{1}{4}$-inch, and the posts being well cleaned from any rust, were twice payed over with coal tar and grease, applied hot.

The Iron was supplied through the Department; and, including cost of same, carriage to Burdwan and labor in manufacturing, the cost of each was Rs. 4-4-3.

L. R.

No. CXLVIII.

PENDULUM OPERATIONS OF THE G. T. SURVEY.

(2nd Paper.)

An account of the Pendulum Operations about to be undertaken by the Great Trigonometrical Survey of India; with a sketch of the theory of their application to the determination of the earth's figure. By CAPTAIN J. P. BASEVI, R.E.

IN 1825, M. Bessel made his experiments for determining the length of the seconds pendulum at Konigsberg, with an apparatus constructed and partly designed by Repsold the celebrated artist of Hamburg. The apparatus was contrived so as to avoid any uncertainty in the centre of oscillation of the pendulum, as well as any error in the measure of its length, by observing the times of vibration of a pendulum ball suspended alternately by two wires, whose difference in length was known.

A toise was set upright on a narrow horizontal plane firmly fixed to a perpendicular iron bar, and the contrivance by which the pendulums were suspended, could be placed either on the horizontal plane, or on the top of the toise itself, so that the effective lengths of the wires differed in the two cases by an amount exactly equal to the length of the toise. The wires, which were of steel, were attached to a thin strip of brass which unwound itself over a small cylinder. The pendulum, thus suspended, described the curve called the evolute of the circle. At the lower end of the iron bar, there was a micrometer screw for measuring small differences in the height of the ball.

The system of observation was as follows:—At the commencement of a series of coincidences with the longer pendulum, the thermometers attached

to the toise were recorded, and the reading of the lower surface of the ball was taken with the micrometer screw; the pendulum was then set in motion, and after a sufficient number of coincidences had been observed, the readings of the ball and thermometers were again taken Exactly the same process was then gone through with the shorter pendulum: then from the times of vibration of the two pendulums whose absolute lengths were unknown, but whose difference in length was accurately known, the length of the seconds pendulum was easily computed.* There were a great many minute details to be attended to, all of which were carried out with the greatest ingenuity and nicety, and all conceivable sources of error were considered and their effects computed and allowed for.

The coincidences were observed in a slightly different way from any preceding method. The pendulum was enclosed in a wooden case, faced with glass to keep out currents of air, as well as to preserve as constant a temperature as possible; the clock was placed about $8\frac{1}{2}$ feet in front of the pendulum, and between the two, the object glass of a telescope was adjusted to form an image of the detached pendulum in the plane of the clock pendulum, to enable them both to be seen simultaneously through the observing telescope, which was set up at a distance of about 15 feet. On the wire of the detached pendulum was fixed a small brass cylinder, painted black, and called the coincidence cylinder; it weighed something under 4 grains, and could be brought exactly opposite the scale for measuring the arc of vibration.

On this scale a black streak was painted, in the middle of which a space was left white, equal to the diameter of the coincidence cylinder, so that when the pendulum was at rest, the cylinder exactly covered it. Again, to the bottom of the clock pendulum a piece of blackened paper was attached, in which a hole had been cut of such a size that when both pendulums were at rest, it exactly coincided with the image of the white space

* Let t_1 and l_1 be times of vibration and length of longer pendulum.
t_2 l_2 " " " shorter "
$l_1 - l_2$ = difference in length $= a$
L = length of seconds' pendulum.

$$\text{Then } t_1^2 = \pi^2 \frac{l_1}{g},\ t_2^2 = \pi^2 \frac{l_2}{g},\ 1 = \pi^2 \frac{L}{g}$$

$$\therefore \frac{t_1^2}{t_2^2} = \frac{l_1}{l_2},\ \frac{t_1^2 - t_2^2}{t_1^2} = \frac{l_1 - l_2}{l_1} \text{ or } \frac{l_1}{t_1^2} = \frac{a}{t_1^2 - t_2^2}$$

$$\text{Again, } \frac{1}{t_1^2} = \frac{L}{l_1} \text{ or } L = \frac{l_1}{t_1^2} = \frac{a}{t_1^2 - t_2^2}$$

on the black streak: hence when the pendulums were moving in coincidence, the coincidence cylinder was visible through the hole, and completely eclipsed the white space. Bessel's result was expressed in lines of the toise of Peru, the standard used in the measurement of the Peruvian arc.

In publishing these experiments, M. Bessel pointed out the true correction for buoyancy, which he had investigated by swinging in air two spheres of equal diameters, but of different densities, one being of brass and the other of ivory, suspended by a fine steel wire; and again by swinging the same brass sphere first in air and then in water. These experiments showed that the old formula for reducing observations in air to a vacuum gave too small a correction, and that it should be multiplied by a factor.

Mr. Francis Baily made a long series of experiments on the correction for buoyancy, which were published in the Philosophical Transactions for 1832. He used about 80 pendulums, all differing in form, weight, and mode of suspension. From these experiments he deduced factors for pendulums of almost every description that have ever been used, and computed also the weight of the air adhering to each, in other words deduced the *vibrating* specific* gravity of the pendulum. He concluded from all his results, that even if a pendulum is formed of materials having the same specific gravity, yet if it be not of an uniform shape throughout, each distinct portion must be made the subject of a separate computation, in order to determine the correct vibrating specific gravity of the whole body, since each part will be differently affected by the surrounding air.

The last extensive series of experiments were those taken in 1828-31 by Captain Henry Foster, who was sent out on a scientific mission by the Board of Admiralty. He took out with him four invariable pendulums of different metals, two of Captain Kater's pattern, and two of Baily's convertible pattern. These last consisted of a plain straight bar, 2 inches wide, $\frac{1}{2}$-inch thick, and 5 feet $2\frac{1}{2}$ inches long, having two knife edges 39·4 inches apart, but no heavy bob or sliding weights, as in Captain Kater's

* "The vibrating specific gravity of a compound pendulum is *ordinarily* found as follows: Let d', d'', d''' ... denote the distance of the centre of gravity of each body respectively from the axis of suspension: w', w'', w''', ... the weight (in air) of each body: s', s'', s''' ... the specific gravity of each body determined in the usual manner. Then will the required *vibrating* specific gravity of the pendulum be

$$S = \frac{w' d' + w'' d'' + w''' d''' + \ldots}{\frac{w' d'}{s'} + \frac{w'' d''}{s''} + \frac{w''' d'''}{s'''} + \ldots},"$$

(*Philosophical Transactions*, 1832.)

pattern; the synchronism was adjusted by filing away at one end of the bar; Baily's intention was, that the pendulum should either be used as two different invariable pendulums, or applied as a single convertible one for absolute determinations, at any station. The objection to the form is, that both the knife edges must be exactly perpendicular to the bar, or error is entailed, as the bar is not flexible like Kater's. Captain Foster swung pendulums at all his stations, 14 in number, which were chiefly in the southern hemisphere. He made a set of observations, at Mr. Brown's house before the voyage; on the return of the pendulums to England, they were again swung at the same place, but by Mr. Baily, Captain Foster having been most unfortunately drowned in the River Chagres, in February 1831, just as his mission was completed. His observations were reduced by Mr. Baily, who obtained from them an ellipticity of $\frac{1}{289 \cdot 5}$.

About this time the Russian government sent out an expedition under Captain Lütke, who used an invariable pendulum, formerly used by Captain Basil Hall. He swung it first at Greenwich, and afterwards at Ualan, in the Caroline islands, Guam, Bonin island (to the south-east of Japan), at Sitka in Russian North America, at Petropaulowski, Valparaiso, St. Helena, and St. Petersburg. He deduced an ellipticity of $\frac{1}{267}$ from his observations.

Shumacher, the celebrated astronomer of Altona, conducted in 1829-30 a series of experiments with Bessel's apparatus, at the castle of Guldenstein, in order to determine the Danish standard, which was to be a certain fractional part of the length of the seconds pendulum, at the level of the sea, in latitude 45°. In order to estimate the influence of the air, he used, instead of a ball, a hollow cylinder of platinum, made by Repsold, inside which a second solid cylinder, also of platinum, fitted perfectly true. The outer cylinder was closed by covers of the same diameter screwing on to it, which were both perforated; the clamp holding the wire was fastened on to the top, and into the bottom was screwed a point with which the contact was made in measuring the height of the cylinder by the micrometer screw.

The pendulum was swung under four different circumstances, viz., the long pendulum, with and without the inner cylinder, and the short pendulum, also with and without it; and as exactly the same surface was exposed to the air in each case, the influence of it could be computed, which was done

by a formula deduced by Bessel. The reduction of the observations was made by Professor Peters. One novelty was introduced, viz., that of computing out the attraction of the ground on which the observations were taken. A square space having a side of 600 toises (1279 yards), in the middle of which the observatory was situated, was subdivided again into 36 squares of 100 toises (213 yards) a side; in each of these borings were made, and specimens of the earth removed and their specific gravities determined; as these were very nearly the same, a mean of the whole was taken. The height of the floor of the pendulum room was 34½ toises (220·6 feet) above the mean sea level, and the attraction of this plateau of the earth's crust introduced a change in the length of the second's pendulum of 0·000215 English inches.

Carlini, whilst measuring the Piedmontese arc in 1821-23, took a series of pendulum experiments at the Hospice on Mount Cenis, with the view of determining the density of the earth. His pendulum was formed of a heavy sphere suspended by a wire, which was attached to a kind of inverted stirrup; in the part corresponding to the foot plate there was fixed a wheel with a sharp edge turning on its axis. This wheel was placed on a grooved plate and formed the knife edge for suspension; the arrangements for observing were similar to Bessel's. Corresponding observations, though not with the same apparatus, were taken by Biot and Mathien at Bordeaux. The result was a density of 4·95.

One more attempt to determine the density of the earth by means of the pendulum was made in 1854 by the Astronomer Royal, Professor Airy, at the Harton Colliery pit. Two invariable pendulums were set up in the same vertical line, one at the top, the other at the bottom of the pit, and their coincidences with the pendulums of two clocks were simultaneously observed, the relative rates of the clocks being determined by a galvanic apparatus. After each series of coincidences the pendulums were interchanged. The distance between the upper and lower pendulums was 1256 feet; a careful description of the intervening strata was prepared, and specimens submitted to Professor W. H. Miller, who determined their specific gravities. The acceleration of the seconds' pendulum below was 2·24 seconds per diem, and the resulting mean density of the earth was 6·565.

The best value of the earth's ellipticity as yet deduced from pendulum observations is undoubtedly that of Mr. Baily's. He combined all the

observations taken with invariable pendulums, and after applying to them all corrections, obtained a mean ellipticity of $\frac{1}{285 \cdot 3}$. The latest value of the same, from geodetic observations, is Captain Clarke's, R.E., which includes the new Russian arc, and is $\frac{1}{294 \cdot 36}$. The ellipticity obtained from observations of precession and nutation is $\frac{1}{303 \cdot 3}$ (Airy's tracts).

The apparatus for the Indian experiments, consists of two invariable pendulums on Kater's principle, a vacuum apparatus with air pump for exhausting, an astronomical clock by Shelton, a good battery of thermometers and a transit instrument. Both pendulums have already done good service; one having been used by General Sabine in his extensive range of experiments, the other by Professor Airy in his Harton pit experiments; they cannot be considered, however, to have retained their original length, as their knife edges have been reground. Each is composed of a bar of plate brass, 1·6 inches wide and rather less than an $\frac{1}{8}$th of an inch thick; a strong cross piece of brass is rivetted and soldered to the top to hold the knife edge, which consists of a prism of very hard steel, passing through the bar and adjusted at right angles to its surface. The prism is equilateral in section, but the edge on which it vibrates is ground to an angle of about 120°; the length of the bar from knife edge to the extremity is about 5 feet $1\frac{1}{2}$ inches. At $3' \, 2\frac{1}{4}''$ from the knife edge, a flat circular bob, also of brass nicely turned and pierced in the direction of its diameter, is firmly soldered on; the part of the bar beneath the weight, called the tail-piece, which is about 17″ in length, is reduced to a breadth of 1·7 of an inch and is varnished black, in order to contrast better with the white disc on the clock pendulum, in the observation of the coincidences.

The knife edges rest on agate planes set in a solid brass frame, which is provided with three levelling screws. On the outer side of each plane are Y's, which are moveable in a vertical direction by means of an eccentric; the knife edges rest in them when the pendulum is not in use, and by their means the observer is enabled to lower the pendulum down gently so as to bear always on the same parts of the agate planes. Each pendulum has its own set of planes, and will give different results if swung on any others.

It has been decided to swing the Indian pendulums in vacuo, in order to secure the following advantages. When the pendulum has been set in motion, it will vibrate for a whole day; its temperature will be more equable; it

will not be disturbed by currents of air; and errors in the formula for the correction for buoyancy are unimportant. The vacuum apparatus consists of a cylinder of sheet copper about 1 foot in diameter and rather more than 5 feet long, with hemispherical caps, the upper one of glass and moveable, the lower one of sheet copper and soldered to the cylinder. The upper end of the cylinder carries a strong brass plate, to which are attached the frames containing the agate planes and a bar of the same metal and shape as the pendulums; placed side by side with a pendulum inside the apparatus, the bar and pendulum will be of the same temperature, and it is evident that thermometers attached to the former will give the required temperature of the latter. Two delicate thermometers are attached to the bar, their bulbs being sunk in the metal at points equidistant from each other and the ends of the bar. The stem of the upper thermometer is inverted, and placed side by side with that of the lower thermometer, in order that they may both be viewed through a moderate sized glass plate let into the cylinder. In the lower part of the cylinder there are four other windows, two on the line of the pendulums, to enable their coincidences to be observed; the other two at right angles to these, to give additional light and enable the observer to ascertain whether the detached pendulum is vibrating truly without wabble. There are two scales fixed at right angles to each other, inside the cylinder, on a level with these windows, one of which is used for measuring the arc of vibration of the pendulum, and the other to measure the distance of the pendulum from the former scale, which is necessary to furnish the correction for parallax in the readings of the arc of vibration: it is useful also in placing the pendulum at a constant distance from the clock, which is found convenient in practice.

The upper 4″ of the cylinder is made of greater thickness than the rest, and at top is a strong projecting flange which is intended to rest on a strong cast-iron frame made in two pieces, so as to grip the cylinder round the thicker part just below the flange; the halves of the frame are then firmly bolted together with nuts and screws. The upper surface of the flange is ground perfectly true to receive a bell glass, the cap already mentioned, which is like the receiver of an ordinary air pump. The eccentric for raising and lowering the pendulum on to the agate planes passes through a stuffing box in the upper part of the cylinder. Motion is imparted to the pendulums by means of a fork and crutch turned by a spindle which passes through another stuffing box.

The clock with which the vibrations are compared is firmly secured to a wall, and the vacuum apparatus is erected in front, at a distance of about 2 feet from it. The diaphragm for limiting the view of the disc is fitted inside the clock case.

The telescope for observing the coincidences is placed on a small masonry pier at a distance of about 8 feet from the vacuum apparatus and is mounted so as to slide laterally on a graduated horizontal bar; it has also a slight vertical motion. The thermometers and barometers are read from alongside of this pillar by means of a cathetometer, viz., a telescope sliding up and down on a vertical rod. The object of this is to obviate the ill effects of any defect in the isolation of the apparatus, as well as the influence of the observer's person on the thermometers.

As the disc on the bob of the clock and the tail-piece of the detached pendulum are too far apart to be viewed simultaneously by the telescope, a lens is placed between them, so as to throw the image of the white disc upon the tail-piece of the pendulum. The vacuum cylinder and all its adjuncts, air pump, &c., were made by Adie, and are the only new portions of the apparatus.

The method of operation is as follows:—After setting up the clock, the vacuum apparatus is inserted in the iron frame and suspended either on wooden trestles or masonry piers; the frame is roughly levelled; the temperature bar is fixed in position; the agate planes are screwed on firmly to their bed plate, and are very carefully levelled by means of delicate spirit levels provided for the purpose. A pendulum is now inserted and let down upon its planes, but the clock must not yet be set in motion. The telescope is next set up on the prolongation of the line which passes through the two pendulums, when both are at rest. For this purpose it is moved laterally on its graduated support, until a very small portion of the paper disc, on the bob of the clock pendulum, is visible on one side of the tail-piece of the detached pendulum. The reading is noted, and the telescope is then moved in the opposite direction, until an equal portion of the disc is visible on the other side of the tail-piece; the reading is again noted, and the telescope is set to the mean position. The pendulum is then removed, and the diaphragm in the clock case adjusted, until its cheeks are tangents to the disc. The pendulum may now be replaced, and nothing remains to be done but to exhaust the air out of the apparatus and to set the pendulums in motion.

The observations are made in exactly the same way as already described in the account of Captain Kater's apparatus; the times of the disappearance and reappearance are both noted, and the mean taken as the true time of coincidence. The arc of vibration is then determined by noting the reading of the arc, when it is cut by the same edge of the tail-piece on each side of the vertical line. The thermometers and barometer are read by means of the cathetometer. It is usual to observe not every coincidence, but the first three consecutive coincidences, and then the 11th, 12th, 13th, then the 21st, 22nd, 23rd, and so on; after observing the first two or three, the times of the after coincidences can be easily computed with sufficient accuracy to intimate when the observer should be ready to note them.

It is intended to have observations made generally along the Great Arc at stations 2″ apart in latitude, and at other points where it may be desirable to obtain data regarding local variations in the intensity of gravity.

The pendulum experiments in this country will afford an independent value of the ellipticity of the Indian arc. It is also hoped that they will throw some light on the existing discordances between the astronomical and geodetic latitudes of the Indian survey.

The amount of the deflections of the plumb line, due to the Himalayas and elevated table lands to the north of India, have been computed by Archdeacon Pratt for the different terminal stations of the Indian arcs; but these determinations are so much in excess of the results of the survey, that it is evident that the effects of the mountain attraction must be in a considerable degree compensated, either by a deficiency of density in the strata to the north, or by an excess of density in the strata to the south, of the survey stations.

Now the pendulum can undoubtedly be made the means of showing whether the compensation is to be attributed to either of these causes; for, whilst the effect of a distant range of mountains on the vibrations would be quite inappreciable, any local variation in the density of the underlying strata would show itself most unmistakably; so that by taking observations both at a normal station, and at a few points in its vicinity symmetrically situated around it, should there be any considerable excess or defect in the density of the strata to counteract the disturbance due to the mountain mass, the pendulum observations would not fail to point it out.*

* Professor Stokes remarks in his letter on these operations: "The pendulum no doubt indicates

The Indian operations will eventually be combined with those taken previously with similar instruments in other parts of the world, to deduce the ellipticity of the earth's mean figure. Both Sir John Herschel and Professor Stokes have remarked, in their letters on the proposed Indian operations, that almost all observations hitherto made have been taken at stations either on islands or coasts, so that a series along the centre of a continent is very much needed. A complete set of observations has been already taken at the Kew observatory by Mr. B. Loewy, with the Indian apparatus; and on the completion of the experiments in this country it will be returned to Kew, in order that final observations may be taken, to show whether the pendulums have undergone any change in the interim.

It is to be hoped, however, that so good an opportunity will not be lost of extending these observations to stations easily accessible from India, though not included within its limits. On this head Professor Miller's opinion may be quoted at length. "Much would be added to the value of the observations made at the stations of the Indian survey, if, before the pendulums were brought back to England, observations could be made with them at some other points, especially points nearer to the equator, such, for instance, as the south coast of Ceylon, Singapore, or on the coast of Borneo. Another accessible point, interesting from being in a long line of depression, where a large gravitation might be expected, is Aden."

The intention of the Russian government, to have similar observations made along the Russian arc, has already been alluded to. If, after the return of the pendulums to England, they were to be swung at one of the Russian stations, it will be possible to combine the Russian with the Indian operations, and deduce a value of the earth's ellipticity from exclusively Continental observations, extending from Cape Comorin to the northermost part of Finmark.

G. B.

only the vertical component of the disturbing force, whereas it is the *horizontal component in the plane of the meridian* that affects the measures of arcs; at any one station, of course, a horizontal disturbance may exist without a vertical disturbance, and *vice versâ*; but in a *system* of stations disturbances of the one kind must necessarily be accompanied by disturbances of the other kind. Indeed it is theoretically possible, from the vertical disturbances, supposed to be known *actually to calculate* the horizontal disturbances, and that without assuming anything beyond the law of universal gravitation. Actually to carry this out, would probably require observation to be made at stations more numerous than can be thought of, but the fact of its possiblity shows how severe a check pendulum observations are capable of exercising on the results of geodetic observations."

No. CXLIX.

ECHAMUTTEE IRON BRIDGE—EASTERN BENGAL RAILWAY.

THIS bridge, of which an Engraving is given in the Frontispiece, crosses the Echamuttee river, just below its separation from the Matabangah river. It has five spans of 80 feet each, being about 16 feet above the highest flood-level, and 42 feet above the water in the dry season. The girders are of wrought-iron, 8 feet deep, resting on cast-iron cylinders, which are sunk 33 feet below the bed of the river, by the pneumatic apparatus, invented by Mr. J. Hughes. The total height of each cylinder pier is 75 feet.

It may not be uninteresting to those unacquainted with the mode of sinking cast-iron cylinders by the pneumatic apparatus, to give a brief account of the method that was adopted in the construction of the bridge.

In the first place, a substantial timber stage is formed across the river, on piles driven securely into the bed. A road-way is then formed to carry two powerful travelling or Wellington cranes; and when these are erected, the lowermost cylinders, which are 7 feet in diameter and 6 feet long, weighing each three tons, are carried to their respective places. The bottom cylinder, having a knife-edge, readily cuts its way into the clayey ground. One or more cylinders are then placed and bolted on to the lower one, precaution being taken that the joints are made quite air-tight. Large boxes of iron weights, amounting in the aggregate, occasionally, to thirty tons, are then put on the top, which by shear dead weight force the cylinder down. This weight however, will not cause them to sink more than a few feet. The pneumatic apparatus then comes into action.

An air-tight cylinder, or "bell," as it is technically called, of wrought-iron, 7 feet in diameter, 9 feet long, and weighing upwards of nine tons, is fixed on to a length of the cast-iron cylinder pier to be sunk.

The "bell" is a cylinder fitted with a wrought-iron cover securely bolted to it. Through this cover two cast-iron chambers, called "air-locks," project $2\frac{1}{2}$ feet above the top of the cylinder, and 3 feet 9 inches below the cover: they are D shaped, in plan, with a sectional area of about 6 square feet.

The top of each air-lock is provided with a circular opening, 2 feet in diameter, and with a flap, working on a horizontal hinge, that serves to close it air-tight when the chamber is filled with compressed air.

The communication from the chamber to the inside of the cylinder is made through a rectangular opening, 2 feet by 3 feet 4 inches on the flat side of the chamber, and has an iron door, working on vertical hinges, to close it air-tight, when required.

The flap is analogous in its use to the lower gate of a canal lock, and the door answers a purpose corresponding to that of the upper gate.

These air-locks are placed upon opposite ends of the same diameter of the cylinder, and the lock doors open so as to communicate with opposite semi-cylinders.

Two light wrought-iron cranes are fixed inside the cylinder, the jibs of which sweep over the space between the air-locks, and extend into the chambers when the doors are open; so that a loaded bucket suspended from the crane may be deposited in the chamber, with the least amount of labor.

A chain passes over the sheaves of these cranes, and round the barrel of a windlass, worked by two handles in the ordinary way; and carries a loaded and empty bucket at opposite ends.

The air-locks are furnished with cocks, communicating from the interior of the cylinder to the chamber, and from the chamber to the atmosphere.

Of these, each air-lock has two sets; one set, accessible from the inside of the chamber, is designed for the use of the men passing into or out of the cylinder, with the view of giving them perfect command over their own movements and of freeing them from dependence upon the attention of others. The other set of cocks is used in passing buckets or materials through the air-locks. One cock, communicating between the chamber and the atmosphere, is placed in charge of a man inside the cylinder, who,

having closed the door, can then let off compressed air, and so pass a bucket from the in, to the out, side.

Another communicating from the interior of the cylinder to the chamber, is worked by a man outside, who has thus the power, on closing the flap, to fill the chamber with compressed air, and to pass a bucket from the out, to the in, side.

The bell is lighted by six strong glass lenses, 9 inches in diameter.

Compressed air is supplied to the cylinder pier by a double barrelled pump, 12 inches in diameter and 18 inches stroke, with double action patent valves, and driven by a 16 horse-power non-condensing engine. The air-supply pipe is 3 inches diameter, formed of iron lapwelded tubes, with hose pipes at the ends, so as to accomodate it to the various positions in which it may be required. The air pipe is terminated within the cylinder by a valve opening inwards, to obviate any accidents that might arise from the bursting of the pipe.

When the nature of the soil, at the bottom of the cylinder in process of of sinking, is such as to prevent the ready exit of the water through the lower end of the pier, it is then forced up a pipe provided for this purpose, and allowed to escape just above the surrounding water level.

Lastly, a windlass is fixed on the outside for the purpose of hoisting the loaded buckets out of the air-locks, and for lowering the empty ones into them or the reverse. This completes the mechanical arrangements of the apparatus.—[*From the E. B. Railway Hand-Book.*]

Rough stone anicuts at the heads of these channels, raise the water level to the required height, the lowest on the Cauvery being 7 feet, and the highest 25. The channels are for the most part supplied with regulating sluices at their heads, escapes for getting rid of flood water, silt sluices for creating a local scour to aid clearances, silt dams to arrest the deposit brought down by cross drainages, irrigation sluices for distribution to the fields, &c.

To enter upon any very detailed account of the various constructive features of each and all of these works as at present found to exist, would simply be a waste of time. I shall therefore confine myself to the most general remarks, pointing out particularly the faults which call for rectification.

As regards the anicuts, I do not think I can do better than quote from the report, sent up to Government in March 1864 with the Estimate for rebuilding the Sreeramadavara anicut across the Hemavutty river, and the work connected with which is now in hand.

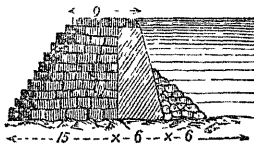
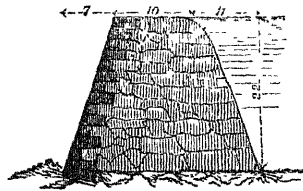
Section A.

"The dam as originally constructed, had a section similar to that shown in the margin A, and consisted of a mass of rubble and large stones; the front casing being composed of stones (about $3\frac{1}{2}' \times 1\frac{1}{2}' \times 1'$), while the aprons consisted merely of large rough stone blocks (averaging $9' \times 3\frac{1}{2}' \times 2'$) laid in uneven courses; each stone projecting about one-third its length, beyond the one above it. All the interstices between the larger stones were filled in, with small and large rubble. From such portions as still exist, it is very clear that the first repairs were carried out with considerable skill and care; the stones were well shaped and laid in regular courses, each course projecting about $2\frac{1}{2}$ feet beyond the upper one.

Section B.

"The repairs during the years 1842-44-59-60, were carried out on a different plan. The general section of the dam was retained, but an attempt was made to divide the dam into three separate parts, viz., the body, the front slope and the rear apron (or as called by the natives, the *narraincuttoo*, *goodercuttoo* and the *soojicuttoo*). The body of the dam was composed of large stones, the largest of which were laid on the top as cap stones. The remaining portion of the dam was constructed with large and small blocks of stone."—*See* section B.

The above is a very fair sample of the section given by the natives to this kind of work, and shows the fallacy of trusting, as before observed, to the size and position of the material instead of to the homogeneity and cohesiveness of the work as a whole Here, spite of the employment of the largest blocks and most skilful application of the material, the dam was breached five times between 1842 and 1863.

Muddoor Dam.

Sreeramadavara Dam.

The remedy is, of course to do away with all loose material; as has been done in the reconstructed Muddoor Dam across the Shimsha, on the section given by Colonel Lawford, and carried out by Captain Johnson, and as now being adopted for the new Sreeramadavara anicut. (*See* sections above.)

The natives having invariably selected rocky sites for works of this kind here, there are not the difficulties of a sandy bed to be contended with; and, consequently, with a sound rock apron, and solid left wall of rubble stone in chunam, there is little to be feared. The chief defect, next to the instability of the native section, is unquestionably the leakiness of works so constructed, which allows all summer water to escape without rising into the channels. They are thus only practically in action, while the rivers are comparatively full.

General Green, while adhering to the native section, successfully corrected this latter peculiarity, by building an impervious brick in chunam face wall against the upper side of the anicut, section C. but a little consideration must show, that while the main constructive defect is left unremedied, this will not suffice. The work still remains exposed to danger during periods of excessive flood. The mere blow of the overfall at such periods, will in time loosen the best constructed rubble-work (soojicuttoo); or a tree, as sometimes occurs, hanging on the work, may do the same. And, once the very smallest stone is washed

Section C.

or torn out, its neighbour instantly follows, and shortly after the mighty flood concentrating with indescribable fury rushes into the gap, tears out the largest masses of stone and transports them as mere straws to any distance down the stream, leaving behind a clean breach. As regards the material of face walls, it is also evident that from the want of clay in the soil, the brick manufactured is very unsuitable for hydraulic works and is readily worn away by water. Crabs moreover drill holes through a wall of this kind.

With the object of decreasing the depth of water flowing over the anicut during flood, and also no doubt to throw the stream at other times directly into the channel heads, the natives invariably carried the work in a curved line, its general direction tending up stream. The length of the work is therefore ordinarily about double the actual breadth of the river. For other reasons also, we find that the crown of the work is at different levels, the part next the head sluice being almost invariably lower than the rest, to relieve the head of water against this work during flood.

All these features, dictated by experience as desirable with the peculiar native section, are so many defects, with the solid watertight work now adopted.

As regards the regulating or head-sluices they mostly consist of a series of rough stone posts (4 or 5 feet apart) with caps, and a parapet wall above, affording means of stopping the openings with rough baulks of timber, brushwood, &c. They fulfil their objects most imperfectly, and frequently the flood enters the channel almost uncontrolled, causing breaches, &c. This inability to regulate the stream, led the natives to place an escape in the channel bank close behind the head-sluice, to divert, as much as possible, the surplus flood which entered back again into the river. This latter work would not be absolutely essential with properly constructed head sluices. It is often a decided weakness.

The channels themselves, as may be premised, are rough trenches, carried round spurs and up to the head of the intercepting valleys, altogether in very tortuous lines to suit the undulations of the country along the river banks, from which, as before explained, they never withdraw to any great distance; partly on account of the rapid side slopes, and partly from defects of levels in original construction. The whole of the irrigation as well as the banks, lie invariably of course on the river side of the channel, and in these banks are placed the sluices (till lately frequently simple

open cuts through the bank itself, called by the natives *muddaways*), as also the escapes at intervals for surplus water.

On the upper side of the channel, the cross drainage from the adjoining high grounds would necessarily enter the channel quite uncontrolled, were it not for rough stone silt dams constructed across them. Where there is no great volume of water, these dams answer fairly, if kept well cleared in rear and in proper order; but with large drainages, they prove quite inefficient, allowing frequently so much silt to be carried into the channels as to choke them entirely and prevent onward flow, thus depriving the fields of all water supply till the obstruction is removed. Sometimes also the cross drainage coming down in unwonted volume, breaches the opposite bank of the channel and brings about the same result. Aqueducts are quite a modern introduction.

In addition to these works, there are solidly constructed outlets at low levels [locally termed *biddigundies*] for scouring out accumulated silt at convenient points; but while an undoubted source of weakness, it is not at all clear that they hold out any adequately compensating advantages.

Lastly, there are the escapes for surplus water, which, being rough stone works precisely similar in character to tank *codies*, call for no special description. It is almost needless to say, that in their present form they are inherently weak.

In addition to the numerous constructive defects of these various adjuncts to the channels, there are others of quite as serious a character, if indeed not more so. I allude to channel offences on the part of the ryots cultivating under them, and whom it is only natural to suppose would be somewhat interested in the preservation of the works, upon which almost their very existence depends. The main defect here has been produced by the system of permitting irrigation direct from the main or trunk canal. Ryots with the smallest patches of ground to irrigate, deliberately cut through the channel bank, and not only took often fifty times the quantity of water actually required, but left an opening, which, unattended to in flood time, became an open breach, stopping all irrigation and entailing great outlay on the State.

This defect has, it is true, been to a considerable extent remedied by the construction of masonry sluices by this Department, and the practice has been followed by the lately constituted Conservancy establishment. Still, however, the direct irrigation from the main channel goes on, and is the

fruitful source of that reckless waste which not only interferes seriously with the profits of the State, but encourages a spirit of almost lawless independence on the part of the cultivators.

As showing the effect upon the revenue, I beg here to append an abstract of the *actual* yield in revenue, compared with what it *should* be, under the measured discharge of the channels in the Mysore division:—

	Length of channels in miles.	Measured discharge in cubic ft. per second.	Capable of irrigating at 40 acres per cubic ft. per sec.	Assessment at 7½ Rs. per acre.	Actual revenue as realized in 1864-65.	Yearly loss sustained by the State
			Acres	Rupees	Rupees	Rupees
	461·5	2,677·5	107,100	803,250	240,250	569,000
Averages per cubic foot of discharge per second, ...	..	1	40	300	90	210

To remove any doubt as to the moderate hypothesis upon which this calculation is based, I may observe that while I have only assumed that one cubic foot of water per second is capable of irrigating 40 acres of rice, it would appear by late experiments of the Madras Government, that 44 acres was the result, without taking into account tail water. On the Eastern and Western Jumna canals, 90 acres, it seems, are irrigated by the same quantity; and the Consulting Engineer of the Madras Irrigation Company, in lately fixing the water-charge, advocated the standard of 144 acres per cubic foot of discharge (*i. e.*, 4000 cubic yards of water for bringing an acre of rice to maturity).

The direct inference is, that from the numerous constructive defects, and the wasteful habits into which the ryots, almost without check, have been allowed to fall, no less than rupees 5,63,000 are lost yearly to the State. I have not the gauged delivery of the channels in the Hassan division, but judging simply from the length, 232 miles, I must conclude that the loss would be half as much again, making in the gross for the Ashtagram river channels [rupees 5,63,000 + 2,81,500 = 8,44,500] a sacrifice of nearly 8½ lakhs per annum. The Cuddoor and Shemogah division channels, though doubtless equally defective in their way, have not been sufficiently investigated to warrant more than general conclusions being drawn. In making the above statement, my only desire is to bring clearly

under view the wide field open to improvement, by adopting such alterations in the works themselves as science may dictate, and by putting a stop to all unnecessary waste of water. But in this, as in the case of the tanks, extensive enquiry appears requisite, to determine the general principles of engineering, as well as legislative, action.

It will here perhaps suffice to indicate the general direction which, it appears desirable that improvement in the works should take.

The first and most important point, is the substitution of solid water-tight anicuts for the old native section, as before adverted to. This change, already initiated in the reconstruction of the Muddoor anicut under Colonel Lawford, and being now extended to the Sreeramadavara dam, would, I have little doubt by the simple force of circumstances and efflux-ion of time, have extended itself gradually to all the old works. But with the present determination of Government to deal thoroughly with all irrigation works, it appears desirable to secure a definite recognition of the principle. I may therefore be excused some further observations on the point.

Leaving entirely out of account the distress and loss to the village communities dependent on these river works, I cannot but think that the certain and frequent failure in weirs so constructed, makes their restoration on the same plan extremely undesirable, if on no other ground than their being financially unproductive. The substitution of the new solid anicuts advocated, would cost, it is true, at starting, about three times as much; but in the *first* place the expenditure is once and for ever; and in the *second*, a weir of this kind, does three and four times the work of the other. With the leaky anicuts and the excessive waste of water now going on, a second and third anicut is always required lower down, to pick up and redistribute the water; which percolates through the upper dam, or is thrown back unutilized from the channels into the river. Nothing of this kind would be required with works constructed on proper principles, and consequently, several existing anicuts could be dispensed with, with manifest advantage financially and otherwise.

The channels drawn from these works might moreover be extended immensely in length, opening up wider sheets of cultivation than has yet been practicable. Above all, from the new anicuts being impervious, every drop of water below their crowns would be passed down the channels, thus affording a certain and constant supply at all times in the dry season, and

allowing such valuable crops as sugar-cane and mulberry, to be raised in addition to rice.

The second point, which is almost of equal importance, is the prevention of irrigation direct from the channels before alluded to. The cure here is to isolate entirely the main channel, placing it under scientific control, and allowing the distribution of water to take place only at certain intervals into secondary channels, from which alone the ryots should be allowed to draw their supplies—to adapt in fact the rajbuha system of the northern canals, to the different requirements of Mysore. The chief distributory or rajbuha, would of course here run everywhere alongside of the main channel on the river side; and delivery into it would be made by a separate and responsible agency, the main channel being fenced off and otherwise protected from all interference, precisely in the same manner as the railway.

As regards the other essential changes, such as substituting proper regulating sluices to all channel heads, providing aqueducts or other means for passing objectionable cross drainages, &c., the necessity for all these improved arrangements are too well recognized to call for any special remark. They have already been initiated and should now be adopted systematically.

I shall only allude to one more general principle, which might with advantage obtain definite recognition. The defective construction of existing anicuts and channels, have led to the water passed down, being wholly expended in direct irrigation. The only instances to the contrary, with which I am acquainted, are the great Chickdevasagur and Muddoor channels, which, in addition to carrying water for direct irrigation, pass down during freshes sufficient extra water for feeding terminal tanks. With shutters on the new description of anicut, and an increased section and bank to the channels, large quantities of surplus water could no doubt be frequently passed down during moderate freshes, and numerous storage reservoirs supplied at the end of the improved channels.

It may, I think, be safely pronounced, that all the existing Mysore channels are improvable to an almost unlimited extent as indicated above, and that in the legitimate development of these works, the most ample and profitable employment of capital may at present be found, without seeking for essentially new undertakings. The materials are to a great extent on the spot, and the population is both fixed, and from time immemorial, accustomed to rice cultivation.

There is, I believe, only one channel in Mysore, which does not appear

to be improvable to any extent. I allude to Poorniah's nullah, before adverted to, which was undertaken in the "hope of introducing into a Hindoo town the holy stream of the Cauvery," and which, even if finished to the full original intent, would have conveyed but an insignificant stream, with "little perceptible motion." From the head at Tippoor Anicut, the total length is some 78 miles, and the excavations are on the vastest scale —a portion of the latter, near the town of Mysore, being 100 feet in depth through solid rock. Failure of funds or other cause, put an end to this gigantic and profitless religious conception.

In quitting this portion of the subject, I would beg briefly to note the number and extent of channels under the Hemavutty and other rivers in Chickmugloor and Cuddoor Talooks, including the minor ones in the Shemogah and Cuddoor Divisions.

Number of anicuts, ...	314
„ channels, ...	444
Gross length of ditto, ...	miles, 501
Gross revenue, ...	Rs. 72,474

It remains only to review briefly the chief works under this head, lately completed or now under execution, before stating what projects it is proposed to bring forward in next Budget.

The chief completed work is the reconstruction of the Muddoor anicut, across the Shimsha river, and 10 miles north of a town of the same name. For section of the work, *see* page 215. The dam is 900 feet long, and raises the water level about 14 feet. It is capped with granite slabs and backed with dressed stone. The channel leading off from the right flank of the work [there is no left bank channel] feeds 8 tanks, including the large Cusbah tank of Muddoor, under which the present assessment is rupees 7,190 per annum. The scheme has by no means as yet received its proper development, but in a report previously submitted to the Commissioner (dated 3rd October, 1865), I was enabled to show, that while the total outlay, all included, should not exceed rupees 92,000, the actual returns, after deducting rupees 4,000 for repairs, ought to amount annually to rupees 41,540, or 45 per cent. on the outlay.

A similar project now in hand for reconstructing the Sreeramadavara anicut across the Hemavatty, near Nursipoor, in the Hassan division, is estimated, for anicut and head sluices alone, at rupees 1,81,000. The length of the dam is over 1,000 feet, and its average height 22 feet—rock

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bottom as in Muddoor. (For section, *see* page 215.) The extension of the old channels has not as yet been estimated for in detail, but it was roughly calculated that their aggregate length would be 80 miles, with a delivery of 400 cubic feet of water per second, and that the total cost of the improvements, including the anicut, would be rupees 3,50,000. Allowing 40 acres of rice land to each cubic foot of discharge, and 6 rupees per acre as assessment, after deducting repair charges, the net receipts would be rupees 96,000 per annum, or over 27 per cent. on prime outlay. It will, no doubt, take some years before this project is fairly worked out, but much of the material is already prepared.

On the great Chickdevasagur channel, two large aqueducts, the Anchayhulla and Lokani, are now in hand, and many other works of restoration and improvement have been completed both in the Mysore and Hassan divisions, with some of still less importance in the Bangalore, Cuddoor, and Shemogah divisions; but they do not call for any special mention here.

As regards the works to be brought forward in this Budget, there is only one which it seems requisite to notice, namely, the project for reconstructing the Marchully anicut, across the Lutchmenteerth river, the old work having been breached in 1863. The new dam on the solid principle will be built above the present site, using, however, the material of the old work. Its length will be 268 feet, raising the level some 12 feet, costing in all rupees 23,889, in which is included rupees 6,000 for a new right bank channel. The returns from this project should be quite as favorable as the Sreeramadavara dam.

It would of course be impossible, with the present information on the subject, to hazard more than a guess at the probable cost of improving the Mysore river works, on the principles now advocated; judging, however, from the work already accomplished and estimated, I should suppose, it would not exceed 30 lakhs of rupees. With the 90 lakhs before approximately estimated for the Tanks, the total would thus be £1,200,000. On the supposition, however, as pointed out by the Commissioner, that the agriculturists themselves would bear a considerable portion of the burthen, not more then £800,000, or at the outside a million pounds sterling, would have to be furnished by the State, in order to accomplish this great, and, as I submit, truly national work.

Only a short time ago, I believe, the amount required (one million) was

actually in hand as surplus deposit, but although a considerable portion has been absorbed in paying the Rajah's debts and investing funds for His Highness's family, there is still a fair sum over; and so elastic has the revenue proved, that last year there were nearly 8 lakhs of surplus after meeting all charges.

The proposal which, with the utmost deference, I would venture to submit for the consideration of His Excellency the Governor General in Council, is, that accepting one million as the probable outlay required for bringing all existing irrigation works up to standard, the actual execution be spread over 10 years; giving in fact an average outlay of 10 lakhs per annum (over and above the normal departmental Budget), which should either be met from existing surplus funds, or by small loans from time to time, as occasion may require.

The raising of wet crops is what the nation can do best and cheapest, besides being the avocation to which all its instincts have tended from time immemorial; and, as I have sought to show, that in the repair and development of existing works of irrigation lies the true method of obviating the horrors of drought and famine, it is only reasonable to conclude, that, while following the dictates of humanity, the outlay thus rendered necessary, happily under the peculiar physical condition of Mysore must at the same time prove by far the most profitable investment that could be made. Inadequately, therefore, as I have brought this vitally important question under notice, I trust that it may command the fullest and most favorable consideration.

I have hardly adverted to the subject of actually new irrigation works, for reasons previously explained. This should, however, not by any means be supposed to indicate either my indifference to such works, or my holding an opinion as to their inadvisability when the means admit and proper opportunity presents itself.

An examination of the Table given in page 212, shows at once the great quantity of water escaping to the ocean, and there can be no question that a large proportion of this could be turned to account in Mysore, without in the least interfering with any vested interests in Madras. This is a subject which was disposed of with great ability in March, 1807, by the then Acting Resident, Major M. Wilks, and the Surveyor-General, Captain C. Mackenzie of the Engineers (*see* their reports, dated respectively 22nd and 21st March, reprinted 1863); and by all acquainted with the subject, it will

I think be unquestioned that, in addition to storage (or rather intercepting) reservoirs at the head waters of some of the rivers, the great streams of the Toonga, Buddra, Cubbany, and others hitherto untouched, might yet be utilized to almost any extent. With the extensive reconstruction of existing works in the next 10 years which I have advocated, and the completion of the great net-work of communications already well advanced, the revenue will, it can hardly be doubted by that time, have received an impetus which will not only render the construction of great new works of irrigation, a matter of comparative ease, but perhaps as great a necessity as the repair and development of existing works is at this moment.

R. H. S.

No. CLI.

DE LISLE'S CLINOMETER.

Reports on the results obtained by the use of DE LISLE'S *Clinometer for Tracing Hill Roads.*

Description of the Instrument.—The drawing represents the first instrument made: it is in two parts, separating at the dotted line in *Fig.* 2.

The lower part can be fitted on in three positions.

1st.—For packing in its case; with the weight *e*, to the left of the mirror.

2nd.—For descending slopes; with the arc and weight *e*, behind the mirror.

3rd.—For ascending slopes; with the arc and weight *e*, in front of the mirror.

In the instruments now supplied the lower part does not draw off, but revolves on the axis of the mirror, and is retained in the required position by a small spring.

The semi-circular arc has two radial bars, one light C, the other *f*, loaded with a weight *e*. For level, set the bar *f* against the stop *g*, and bring the light bar C, home in the groove formed for its reception in the weight *e*, see *Fig.* 1. For a slope of 1 in 50, leave *f* against *g*, and move the light bar C against the stop *h*, as shown by dotted lines in *Fig* 1.

For any other slope, leave the bar C against the stop *h*, and set the bevelled edge of bar *f* to the required division on the graduated limb of the arc; see *Fig.* 3, where the instrument is set to 1 in 20.

In practice it should be remembered, that a flatter slope should be used in tracing than that intended for the finished road, in order to allow for

the increased slope due to flattening the curves of the line; thus for a road at 1 in 20, the instrument should be set to 1 in 21 or 22, according to the nature of the ground.

In using the instrument, a levelling staff with sliding vane is convenient. The vane on the staff must be adjusted to the height of the observer's eye. The observer stands at the initial point of the trace and sends an assistant forward with the staff to any convenient distance; the observer then holds the instrument up by the ring, and makes his assistant move the staff up or down the slope of the hill, until he gets the reflection of the pupil of his eye in the mirror and the vane to coincide, as indicated in *Fig.* 2. A peg is then driven in at the foot of the staff. The observer moves forward to this peg and sends his assistant on for the next station, and so on.

In taking cross sections of streams, the instrument should be adjusted for level, and the vane on the staff moved up or down at each station until the requisite coincidence is obtained. The level is then read off on the staff and entered in the usual manner.

In windy weather, it may be convenient to suspend the instrument in a wooden box, with sight holes. The box should be mounted on a light staff, and the vane on the levelling staff must be set to the height of the mirror.

When the line is pegged out, and considered satisfactory, a gauge path should be cut, and the line surveyed either by theodolite or spirit level for the plans and estimates.

The great advantage of this instrument, will be found on Ghaut lines along steep cliffs, where a theodolite could not be taken without much risk of injury. It will also save the tedious labor of setting up and levelling a theodolite at numerous successive stations.

The ingenious arrangement of the arc and radial bars is the invention of Mr. A. Cooke, of Messrs. T. Cooke and Sons, 31, Southampton Street, Strand, London.

From LIEUT. DUCAT, *Executive Engineer, Northern Konkan, to* LIEUT.-COLONEL DE LISLE.

I beg to return the clinometer you lent me, and to forward a report on it by Lieut. Osborn, R.E.

I have seen the country over which Mr. Osborn has been working, and can testify both to the very difficult nature of the ground and to the highly satisfactory results obtained by means of your clinometer.

In a hilly country like the Konkan, this clinometer is of inestimable value, and I hope after Mr. Osborn's report, that Government will be pleased to furnish at least one for the use of this office.

Lieut. Osborn's Report.

The Ghauts over which I have used the instrument lie between the villages of Ghowk and Warsaee; the Khind, through which I propose to carry the road joining those two places, being just under the hill fort of Maneckghur. When I first began to use the instrument I was not sufficiently acquainted with the difficulties that might arise from the nature of the ground, and thought that sufficient accuracy would be attained by merely taking the inclination of the slope between my own eye and that of another man whose height was the same. This answered sufficiently well as long as the slope of the hill was not great, nor the jungle dense, but when I came to more difficult ground, serious errors arose from the impossibility of standing erect. Accordingly, I prepared two staves made of strong and straight bamboos. Each staff was about 7 feet long and cut off square at the bottom, so that it might not sink into the earth. To the staff I myself carried, was firmly fixed a small bamboo about 3 feet long so as to form a cross, and at such a height that, resting my right hand (on the fore-finger of which I carried the instrument) on one end of the cross piece, and holding the other end in my left to keep the staff perpendicular and often to form a support, I could see comfortably into the reflecting glass. To the other staff I attached a cross piece only one foot long, but at such a distance from the lower end of the staff, that when I placed both staves side by side on level ground and held the clinometer in the working position, the short stick was exactly the same height from the ground as the mirror of the instrument.

This second staff was carried by a native, whose only instructions were to hold the staff perpendicular on any given point; then setting the instrument to the required slope and moving my own staff till I brought into one line my eye, its reflection, and the cross piece of the second staff, I had only to make a mark on the ground where I held my staff; a line joining the two points on which the staves were held would of course be

parallel to the line joining my eye and its reflection, and therefore at the required slope to the horizon. By this means I found that I could work with the greatest accuracy and very quickly, driving in pegs at each point where the staff rested. These served both to mark out the line and as points on which the other staff should be held. With this instrument I marked out the line for a trial-path, putting in pegs enough for the men to work from, at the rate of a mile in about 6 hours, through very thick jungle and across very steep slopes; in open country of course it is far quicker work. As to the accuracy obtained, the error in a slope of 1 in 33 for a distance of 430 yards was 1·5 inches; I should state that this was in thick jungle where it was impossible to see more than 30 or 40 feet, and the slope of the hill was very steep and difficult to stand on.

It is impossible to over estimate the assistance afforded me by this instrument. A trial-path which would have taken me weeks to lay off with the chain and level, (inasmuch as I should have had to cut down the jungle and dig regular platforms on which to place the instrument,) was laid off in a few days and with, I believe, quite as great accuracy. The only mistakes that can arise, are from the accidental slipping of one of the cross pieces and from the moving of either of the arms of the instrument. It is only requisite to take a glance at the instrument while the hand rests on the cross piece to ensure its accuracy. In working up hill it would add to the ease with which this is done, if both sides of the arc were graduated. I find that the mirror is a little affected by the heat, the coating of quicksilver being injured, but I have used the instrument mostly in the very hottest part of the day: probably neither the morning nor evening sun would be strong enough to affect it so. I can only add that the ease and quickness with which the instrument is used, have made the laying out of the trial-path a pleasure to me, and I should feel much like *Pegasus* deprived of his wings, had I to do another trial-path of the same kind with the level and chain, instead of the clinometer.

From LIEUT. J. BROWNE, R.E., *Executive Engineer, Kangra Roads Division, Punjab.*

I have several times tried the instrument in the most difficult ground I could select, comparing the results obtained with the pegs laid out

on the hill side with a spirit level. As the instrument would have saved me a vast deal of labor and trouble, I did my best to obtain good results from it, but found it quite untrustworthy. In laying out half-a-mile of slope at 1 in 20, the instrument differed from the spirit level 32 feet; and I therefore cannot recommend it for road making, except of the very roughest description. A gunner's quadrant tied to a stick is equally portable, and gives far better results, differing only $2\frac{1}{2}$ feet in the same distance from the spirit level. I do not think the instrument will ever be found to be of any practical use.

From the Executive Engineer, Salt Range Division, Punjab.

The instrument answers very well, but in the opinion of the undersigned, is not so convenient as "Bow's Gradient Indicator,' which is merely a spirit level in a wooden case, the latter 6 inches long, $1\frac{1}{2}$ inches deep, and 1 inch wide; at the end there is a piece of window glass protecting cross wires suited to several gradients, and at the other end a piece of black wood pierced with upper and lower eye holes.

Inside the case, fixed at an angle, there is a mirror which reflects the state of the spirit level. This simple instrument can either be fixed on a tripod, held in the hand like a telescope, or pressed against an alpenstock at the same height as the poleman's vane. It has this great advantage over the instrument under reference, that it is little influenced by wind.

The indicator can be carried in a holster attached to the surveyor's waist belt, and is ready for application without any preliminary adjustment.

From the Superintending Engineer, Assam Circle.—Cherrapoonjee, 29th September, 1866.

I forward Lieutenant Hills', R.E., report on the hill tracing instrument received.

I have tried the instrument myself, and think it handy and useful for Military reconnoissance and marking out trial lines; but for accurate tracing of roads on a selected line through the hills, I prefer the common clinometer.

A cross wire to the mirror frame, and the doubling the size of the instru-

ment, as suggested by Lieutenant Hills, R.E., ; also the addition of a tripod stand, would be improvements.

Lieut. Hills' Report.

I have not had many opportunities of testing the instrument, but from the little experience I have had in working it, I consider it an ingenious and tolerably handy instrument, and well adapted to determine, if a certain point on the face of a hill is accessible at a certain gradient, or what gradient is required to reach that point.

I do not, however, consider that it possesses any peculiar advantage over the ordinary clinometer in use in hill road making, and I question if one could work as accurately with it as with the clinometer.

I think the instrument would be improved if it had a hair or wire attached to the diagonal of the mirror part, and if it were twice its present size.

From Stanley Alexander, Esq., *Assistant Engineer, Bundelcund Road Division.—Nowgong, the 24th November,* 1866.

The clinometer used by me on the Nugaha Ghaut, I found to be most useful, in that it saved me a great amount of labor in tracing the line down the hill side. Having set the instrument to the required decline, no further trouble was entailed than great care in its use to avoid going astray. Not having a proper staff with cross vane I cut a light rod to a length corresponding to the height of my eye. The bark peeled off the head of this made it sufficiently conspicuous, and it was moved up or down the hill, at 50 feet distance, till the proper position had been attained. One great advantage consists in the facility of altering the gradient to suit the nature of the hill.

The instrument however appears to me to be too light for the work. The ground on which I used it was very rocky, and consequently my hand was not very steady. In fact, I found it necessary to carry a staff, which I held simply in order to steady the instrument. The slightest wind also affects it, and renders work impossible during its continuance. I imagine that the box recommended to be used during wind would not answer; as if the apertures were too large, the wind would get in, and if small, the instrument, delicately suspended, would be liable to turn, and consequently the mirror would not face the eye. I fancy if it

were made about three times as heavy as it now is the objections would be removed in a great measure, especially the vibration caused by the unsteadiness of the hand on difficult ground; I should also recommend that the body of the instrument be suspended from the ring for the finger by a small chain about an inch in length. This would render it more accurate.

Also that the diamond cut in the brass be bisected horizontally by a strong wire to guide the eye.

Under favorable circumstances with good smooth ground, and no wind, I do not see why a very fair degree of accuracy could not be got out of the instrument. Nothing could be better for tracing out a line on steep hill sides, when 50 feet cannot be seen and the planting of a theodolite among the rocks is a matter of no small difficulty.

From CAPTAIN F. W. PEILE, R.E., *Superintending Engineer, 1st Circle, N. W. Provinces.—12th January*, 1867.

The line of road, 16 miles in length, from Chokarata to the valley of the Oomlao river, lately surveyed with the theodolite, coincides very nearly with the trial line taken out by Lieutenant Bisset in June last, with the clinometer sent to me to be reported on. This test was necessary to ascertain what dependence could be placed on the accuracy of the instrument.

It appears to me that for running trial lines in hilly country, before engaging in more perfect instrumental observations, and for filling in details of lines of which the courses have already been determined, the instrument is well adapted.

Some practice is required before an observer will be able to work with any degree of accuracy with the clinometer. In holding the instrument close to the eye, the reflection of the pupil in the mirror is large, whilst the vane on the levelling staff at 100 feet distance only appears very small; and if care is not taken in every observation to bring the vane and the centre of the pupil into range, considerable errors will result.

On the whole, from its portability and the rapidity with which observations may be made, even on very bad ground, I consider the instrument valuable, and would recommend its use wherever trial lines have to be run for projected hill roads.

I do not, however, think it would be safe to place it in the hands of

from the right bank (between the bridge-of-boats and Jehangeer's tomb) across the river, so as to check its course, and protect the bank, threatened. These spurs were constructed in the following manner:—

A place on the right bank marked A [*Plate* XXXIV.], (where the ground was firm and somewhat elevated), having been selected as the starting point of the first spur, a strong moonj rope, 1,250 feet long, 10 inches in circumference, and of a strong tight twist, was stretched into the river, on poles, along the line AC; the end C, being secured to a heavy crib anchor, $10' \times 10' \times 10'$; and the end A, which stretched as far as D, 250 feet inland, was firmly fastened to a beam of deodar wood, about $14' \times 8'' \times 8''$, buried horizontally in the ground at a depth of 5 feet, and placed at right angles to the direction of the rope.

The poles on which the rope was stretched, were driven from 4 to 6 feet deep into the bed of the river, and were from 10 to 20 feet apart, The rope was fastened to the heads of these poles, and was further secured in its position by anchors,* each $6' \times 6' \times 6'$ placed at every 20 feet; and when it was thus firmly secured in its position, trees were fastened to it at short intervals, with moonj ropes passing through holes made in their butts. Large trees were placed where the stream was deep and rapid, and small ones near the bank, where the water was shallow.

After the spur was thus got in position, numbers of other trees were fastened to the *main* rope, so closely together, as to form a dense line of considerable substance, which had the appearance shown in the rough sketches, of which *Fig.* 1, *Plate* XXXV., is an enlarged plan of part of the spur; *Fig.* 2, its longitudinal elevation; and *Fig.* 3, its cross section; A, A, &c., represent anchors; the firm arrow lines show current of river before the spur was constructed; dotted arrow lines, after the spur was put up.

After the above spur was completed, a second spur 600 feet long was constructed at BE, in exactly the same manner as the first, to check the course of the river above, and thereby help the lower spur. The ends of the main cables of these spurs, near their starting points, were thoroughly secured, so as to prevent their being turned by the river.

* The anchors are similar to those used for anchoring the boats of a bridge-of-boats, but somewhat heavier; and are made of bullees and net-work of moonj ropes, filled with broken bricks, and masses of pucka masonry. They are fastened to the main rope, with a well-twisted moonj rope of 6 inches circumference. 100 feet of such rope is used for each anchor.

When these spurs were started, the river flowed immediately below the right bank; but as the spurs were pushed into the river, and lengthened from time to time, the current below them, gradually ceased, depositing large quantities of silt, and forming shoals, which afterwards turned into large sand-banks [*Plate* XXXIV. and XXXVI.], and the final result is, the complete turn which the river has taken in its course, as shown in *Plate* XXXVII.

These spurs affected the river not only below them, but also for a long distance above. The current meeting with a check in its course at the spurs, was dammed back for a long distance, and the bed of the river was silted up, both *above* and *below* the spurs.

The above spurs, after having been put up, required constant repairs and attention. Every flood that came down the river, turned and twisted their ends which projected into the river, and caused gaps in them in certain places, which were repaired immediately after the flood went down a little; and the whole of the spurs restored to their original state in about a week after every flood, so as to resist the river more effectually in the next floods.

The river has been checked in its course in this way since April 1865, and the right bank, which was threatened in 1864, has now been completely protected. Also, the land, upwards of 300 acres in area, which was encroached upon by the river during the last 12 years, has been reclaimed and rendered fit for cultivation again. The spurs have, therefore, proved advantageous, both to the people and the Government; the former will derive profit from the cultivation of the land reclaimed, and the latter, get an annual addition to the revenue, in the shape of land-tax on the reclaimed land.

Spurs of the above description, cost about Rs. 3 per foot run at Lahore, and answer best for large rivers. But on small nullahs and petty streams, the same result can be obtained much more cheaply by putting up spurs made of stakes of bullees and broken bricks.

In 1865, a small branch of the Ravee, which flows to the north of Lahore, about a quarter of a mile from the city, set towards its right bank above the pucka bridge on the Grand Trunk road [*Plate* XXXVIII.], and threatened to breach the road behind the right abutment of the bridge.

To stop this tendency of the stream, and to protect its right bank and

the road from the action of the current, three spurs, each about 50 feet in length, were put up at A, B, and C, on the right bank, projecting into the river at an angle of about 45° with the current, and constructed in the following manner :—

Strong stakes of bullees 8 to 14 feet long, were first driven (from 4 to 6 feet deep in the bed of the stream) in a row, as close as possible, round the place selected for each spur. The stakes after having been thus driven, were fastened and secured to each other, with strong moonj ropes and fascines; and then the space enclosed, was filled up with broken bricks and masses of old pucka masonry, and the work was complete. The bank above the right abutment, was also protected in the same way, with a row of stakes of about the same length as for the spurs, driven from 4 to 6 feet deep into the bed of the river, and broken bricks filled in the space behind them. The bank of the nullah between the spurs, was also sloped back, and the foot of the slope protected with a row of stakes, driven flush with the bed, and their heads secured together, with ropes and fascines.

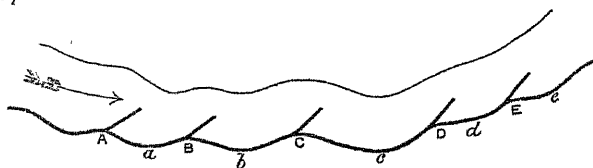
The result of all this was, the *complete silting up* of the stream *between the spurs*, and the formation of a new bank, shown by the dotted line *a, b, c, d.* The old bank was protected, the road saved from being breached through, and the nullah straightened and confined to a channel, the water in which flowed *straight* on to the pucka bridge.

Similar spurs were tried at one or two other places on the same nullah, and proved most effective in protecting the bank below them.

These latter spurs cost Rs. 2 per foot, but wherever old bullees and broken bricks or masses of old pucka masonry can be obtained cheap, the cost can be very much reduced.

Both the above kinds of spurs require to be very firmly secured to the bank; because, so long as the starting point is secured, the spur is certain to produce its effect on the river, but if the river gets *behind* the spur, it is sure to wash it away. Great care should therefore be taken in securing the starting point and keeping the spur in repair, from time to time, so that it may always be in a state to resist any sudden floods in the river.

The following few particulars regarding the position, direction, and length of the spurs, may also prove of use to persons who have not had experience of this kind of work.

No exact rules can be laid down; but experience shows that to protect a bank, or turn the course of a river, the spurs should be put up *above* the bank to be protected, at such places where the river has even the least turn or tendency towards the opposite bank. For instance, in the sketch below, the spurs should be put up at A, B, C, D and E, but never at *a*, *b*, *c*, *d* and *e*. The *least turn* in the river, from the bank to be protected, should be taken advantage of; and for this purpose, the course of the river, for some distance above the place required to be protected,

should be first carefully inspected, or an accurate survey made thereof, and any points similar to these shown above (which should also be somewhat elevated and firm), should be made the starting points of the spurs.

With regard to the direction of the spurs, it has been found in practice, that spurs which project into the river at an angle of 45° with the current, prove more effective and economical than those placed at any other angle; spurs placed at an angle of less than 45° are less expensive, (as they are less liable to damage from the river, and thereby require less repair subsequent to their first construction,) but less effective; while those placed at a greater angle than 45°, are a little more effective, but very much more expensive, (owing to their being more liable to damage from the river, and requiring very heavy repairs to restore them).

The spurs should, therefore, be placed making an angle of about 45° with the current.

With regard to length, spurs required to protect a bank, may be made one-fourth or one-third the length of the bank requiring to be protected; but it is scarcely practicable to name the length of a spur required to *turn the course* of a river. Spurs for this purpose should first be made about 1000 *feet long*,* and *lengthened* subsequently, till the desired end is attained.

The trees for the spurs should not be very small, but of sufficient size

* This must depend so much on the size of the river, width and strength of the current, and a variety of other considerations, that it is hardly possible to name any particular length.—[ED].

to have some effect on the water impinging on them. The trees should be of "keekur," or some similar wood, which is heavy, and will not easily rot.

If the tree spurs are required to last for some time after the immediate end, for which they were put up, has been attained (*i. e.*, if they are to be kept up as a protection to any future possible attack of the river), chain cables of iron, $\frac{3}{4}$-inch diameter, should be used in place of the moonj rope. The iron chain being much heavier than rope, will require to be stretched either on pucka masonry pillars built on wells, sunk to some 25 or 30 feet below the bed of the river, or on piles of deodar or sál wood, 12″ × 12″, and driven not less than 25 feet into the bed of the river. If pucka masonry pillars are preferred, they should be not more than 100 yards from each other; but if wooden piles are used, the intervals between them should not exceed 100 feet.

The tops of the pillars or piles* should be from 3 to 6 feet above the bed of the river, and the chain cable, &c., be well secured to them, so as to be beyond all chance of sinking into the river; for if it does sink, it will soon get imbedded in the sand, and be irrecoverably lost.

Where iron chain cables, supported on pucka pillars or piles, are used, there will be no need of the anchors, that are required to keep moonj rope cables in their position.

The cost of spurs with iron chain cables supported on pucka pillars, will be about Rs. 5 per foot run; and the same with wooden piles, Rs. 4 per foot.

K. L.

* Pillars or piles above the bed of the river, will be required only where the spurs have to be put up *in water*, and their height will, in a great measure, depend upon the depth of the water; but if the spurs are required to be put up in the *dry bed* of a river or nullah, the chain cable may be laid *simply* on the bed, and secured to wells or piles, in a proper manner; and then trees may be fastened to it, as described above.

No. CLIII.

THE MADRAS RAILWAY.

Abridged from the Transactions of the C. E. Institution of Ireland. By T. H. Going, Esq.; *and from the Proceedings of the Institution of Civil Engineers.* By Bryce McMaster, Esq.

Madras was the latest of the three Indian presidencies in entering upon the construction of railways; the first having been inaugurated in the summer of 1853. This is now known as the South-west Line, and runs from Madras to Beypoor on the West coast, thus giving a direct railway communication across the peninsula. Not that Beypoor can boast a harbour superior to any other river-mouth along the coast; for they all, more or less, share alike the natural effects of sand-bearing currents, which, checked by the action of the south-west monsoon, create a bar across their entrances. There is not a harbour along the west coast, from Cape Comorin to Bombay, which can afford security to vessels of any considerable tonnage, except, perhaps, Sedasheghur, where a barrier of coast islands might be so connected, by artificial means, as to constitute a good harbour, sheltered from the effects of this reflux of sand. Beypoor is in fact an open roadstead, and was probably selected for the terminus chiefly on account of the Iron Company, which the existence of extensive beds of rich hematite in this locality called into being some years back, and whose works, now in a semi-ruinous condition, stand as a costly proof that in the absence of a local supply of fuel the manufacture of iron is not a profitable speculation.

For many miles after leaving Madras the line traverses a flat country

of no great geological interest. Everywhere beneath the soil the great underlying stratum is decomposed granite, which becomes more and more consistent in proportion to the depth,—as may be readily observed in the deep wells for irrigation purposes, so frequent in Indian cultivation,—till it finally merges into solid rock, yielding only to the quarryman's art. These sections would lead one at once to conclude, from the texture of the material, and veins of chloride, quartz, &c., which they display, that this decomposed stratum is the result of decay gradually advancing downwards with the lapse of time, and do not anywhere indicate the character of drift.

When undulations of the surface of the ground necessitate railway cuttings, it is generally found that the nucleus of the cutting is the ridge of a greenstone dyke, of which the upper portion is more or less decomposed. It may be supposed that in a country of this character, clays, valuable for pottery uses, will be encountered, as indeed is the case; and the railway cuttings have laid bare some fine deposits of cayolin and other clays, which are turned to useful account in the School of Arts at Madras. Further west, near the Poiney river, gneiss rocks begin to show, diversified by numerous trap-dykes and granite veins of all sizes. This character continues till within a few miles of Salem, where the line cuts a bit of ground intersected by veins of carbonate of magnesia, the so-called "Chalk hills." Near Sunkerry Droog, and again near Coimbatore, it crosses some not very extensive bands of metamorphic limestone.

The great geological feature along the eastern part of the line is the magnetic iron hill near Salem, close to the southern slope of which the line runs for about six miles. The ore from this hill supplies the Porto Novo Iron Company.

The next remarkable feature in the geology of the railway, as we proceed westward, occurs after crossing the Cauvery river, and approaching the foot of the great triangular spur of the western ghauts, known as the Neilgherry hills, round the southern skirt of which the line curves towards the west coast. These hills are a solid mass of gneiss, cut up with dykes in all directions; and the railway through that district has the same tough substance to encounter in many of its cuttings.

There is a peculiar deposit known as *Laterite*, which occurs indiscriminately in all parts of Southern India, and is probably not referable to any special geological period; but which reaches its greatest development on the

BOMBAY.

Belgaum

M Y S O R E

T E R R I T O R Y.

ARCOT

MADRAS

CALICUT

COIMBATOOR

NEGAPATAM

western coast, where it may be seen composing the entire mass of hills, some hundreds of feet in height. It may be described as a gritty, porous clay, indurated by ferruginous infusion. It is massive and easily worked, though at the surface very hard for some inches in depth. It is used for building purposes in the place of bricks (as the derivation from the Latin might suggest), being cut out in blocks, which are further shaped by means of a hatchet. Of course, in a climate subject to frosts, the use of such a material in building would be out of the question; and even in India it can hardly be considered as a material of sufficient durability for railway building, except it be for stations and small drains. It is also used as ballast.

From the foregoing remarks it is evident that there is no lack of good material for railway construction across the southern peninsula. Even throughout the plains of the Carnatic, there are few localities in which a granite quarry, within tolerably accessible distance, may not be looked for. In some instances the mere stripping of the soil for a few inches of depth reveals the surface of a granite plane many acres in extent. The writer is not aware whether it may be considered as one of the characteristics of granite, that near its surface it is disposed in successive layers, analogous to the coats of an onion; or whether, when such a character is observed, it should not be rather attributed to the effects of aqueous deposit than the action of cooling. It is certain that the so-called granite of the Madras presidency may be thus raised in successive layers of varying thickness, and hence it is doubtful whether it should not be regarded as gneiss.

The mode of quarrying granite in the Madras presidency is peculiar, and a description of it may be interesting to those unacquainted with the process. There is in India a caste of people known as *Wudders*, who may, in general terms, be described as the navvies of India. They are of two classes—those who work in stone, and those skilled in the manipulation of earth. Arrived at his quarry, the Wudder's first care is to lay in a stock of firewood, which he cuts in the jungle and removes by means of a peculiar bandy or cart with low wheels of solid timber, drawn by a pair of buffaloes—an important part of his equipment, which was omitted before in the list. The wood is piled in small quantities on the surface of the rock, and ignited, usually during the night, their favorite time for work. After the fire has been steadily kept up for some hours, the upper layer of the

rock expands sufficiently to produce a separation from the substratum. The separation is accompanied by a dull bursting sound; and the extent of the severance is ascertained by a series of taps with the crowbar, the response of which is conclusive to a practised ear. The next operation is to break up this loosened bed of rock into fragments of a size convenient for handling, and this is effected by means of a round boulder of greenstone, as large as can be lifted to his head with the assistance of another man. This he dashes down with all his might on the rock, and sometimes succeeds in making a fracture with a single throw; but it often requires to be repeated many times; and it is wonderful, considering the clumsiness of the method, with what success he turns out handsome square blocks of stone, of dimensions well suited for building. This, however, is more to be attributed to the natural tendency of the stone to square fracture, than to the skill of the Wudder. The greater part of the earthwork in Madras presidency, on the railway, in tanks, &c., is done by people of the same caste as the stone Wudders just described; and these people always perform their work by contract.

In speaking of the materials for construction, a few remarks on lime will be proper. The slight development of limestone in the Salem district has already been mentioned; but for burning purposes the concretionary carbonate of lime common throughout Madras is most used.* In this form it occurs in beds of varying thickness, as well as disseminated through the soil and over the surface of the ground. The nodules are of various sizes, from that of a pumpkin down to the bulk of a pea. A very common variety is shaped like the ginger root, and this is always found to possess slightly hydraulic properties. In the neighbourhood of Madras, as well as on the west coast, almost the only kind of lime used is procured from the burning of shells found in beds a little below the surface, in low lands near the sea coast. The lime made from these shells, being very fine and white, is admirably suited for plaster, and is susceptible of a high polish, which is administered during the period of its setting by means of a smooth stone or crystal, rubbed assiduously over the surface so long as any dampness remains; a little of the powder of soapstone being sprinkled on to assist the polish. Most of the public buildings, as well as the private dwellings, in Madras are finished in this way; and when the work is new it gives the effect of white marble. The action of the atmosphere, however, soon tar-

* This I presume is *kunkur*.—[ED].

nishes the exterior of buildings thus finished, and they look shabby enough after three or four seasons; but the interior preserves its beautiful purity of appearance.

It may be in place to observe, while speaking of lime, that that used for building purposes in Ceylon is all produced from the calcination of coral. Indeed, on the coast, the buildings are mostly constructed of coral blocks, cemented by mortar, of lime made from coral.

The average annual fall of rain in Madras, on the eastern side of the peninsula, is about 50 inches, but as much as 80 inches have been registered as the fall for three several years since the commencement of the century. Within a single month the rain gauge has indicated a fall of 42 inches; and on the 25th October, 1857, 12 inches of rain descended from the clouds in a steady pour of 12 hours' duration. From these data it will be understood, that the question of drainage is one of some importance in the construction of a railway across such a country. The rivers, indeed, constitute the principal difficulties to be overcome, all the more so from the fact that being, during the greater part of the year, little more than broad shallow channels of sand, the great proportion of their duty is concentrated into the short space of a few weeks, during which the rains of the north-east monsoon descend. Those of the west coast must however be excepted from this general description, because the cloud-barrier of the western ghauts, whilst arresting the eastward progress of the south-west monsoon, pours back its deluge of waters to the ocean which washes the shores of Malabar; so that while this vapoury region monopolises all the waters of that monsoon which come laden with the moist breath of the Indian ocean, the Coromandel coast must content itself with such watery stores as are picked up by the north-east monsoon in its shorter flight over the bay of Bengal. A corresponding difference of climate accordingly characterises the country on the two sides of the western ghauts. Innocent of water as these sandy channels of the east appear, however; when the question arises of laying the foundations of a bridge, this uncompromising element is found but to lie dormant within a few inches of the surface of the sand.

The engineers of the Madras Railway have not taken kindly to the ordinary Indian system of well foundations, and it has been only resorted to in a few instances. In laying the foundations of the granite bridge over the Naggery river, of thirteen 40-feet arches, on the north-west line of the Madras Railway, the resident engineer, Mr. Smart, adopted the method of

curbs. The curb consisted of a strong teak frame 40 feet by 9 feet, divided by cross scantlings into five compartments of 4 feet square, and equidistant. The thickness of the curb from under side of beams to upper surface of planking was 2 feet. It was placed accurately above the site of the pier on the surface of the sand, and the masonry built to a height of 10 feet; making an entire height including the frame, of 12 feet; this being the depth of sand above the solid substratum as ascertained by a pricker. Cross walls partitioned the structure into 5 cells, corresponding to the compartments of the curb on which it was built, and every course of the upper 4 feet had layers of hoop-iron worked into it longitudinally. It was then ready for sinking; a diver being set to work in the bottom of each cell to remove the sand, and hand it up by lifts to the top, where it was discharged. The sinking too, was found to be greatly facilitated by keeping the sand well cleared away round the exterior. After being sunk some feet, a crack appeared in the masonry, which alarmed the divers; and it was with difficulty they could be got to proceed with the work. The structure went down in sudden jerks of a few inches at a time, and was finally deposited on its resting-place below the sand within ten days from the commencement of the sinking; and though a few cracks showed in the masonry, it was of no practical consequence. The total cost of the curb, for materials and workmanship, was about 130 rupees, and the sinking cost 90 rupees; 220 rupees, or say £22. The cells were finally packed with stone, which was then grouted, and a level platform thus prepared for the superstructure. Such a mode of getting in foundations would of course be only practicable where the sand was free from boulders.

The principal rivers crossed by the south-west line are the Cortiliar, the Poiney, the Goriathum, the Palar, the Cauvery, the Thootha, and the Kuddulhoondy. It was originally comtemplated to cross all these rivers by means of arches of masonry. A great improvement has however been introduced by the substitution in many cases of wrought-iron girders, whereby the number of costly and tedious pier foundations is diminished. The total length of the south-west line, from Madras to Beypoor, is 405 miles, and the summit height attained at Mooroor, near the foot of the Shervaroy range, 1500 feet above the level of the sea. At Coimbatore, where it passes near the base of the Neilgherry range, a second summit of 1301 feet above the sea is attained; and between these two, intervenes the

deep valley through which the rapid Cauvery washes its way southwards. The elevation of this, at the point of crossing above the sea level, is only 495 feet. The gradients are for the most part favorable, the maximum being 1 in 60, necessitated in descending from the last-named summit towards the plains of Malabar.

Only the south-west line of the Madras Railway has hitherto been mentioned—as being that for the construction of which the company was originally raised, and which is now nearest to completion. In August 1858, the Government entered into a further contract for the construction of the north-west line, which is designed to strike out from Madras in as direct a course as is expedient, towards Bombay, and form a junction with the railway from that town, near Moodgul, in the territory known as the Raichoor Doab, lately restored to the Nizam of Hydrabad. Two branches, one to Bangalore, the other to Ootacamund, have also been sanctioned; but construction has only been commenced on the former. The object of these lines is to give ready access to two such important stations, Bangalore being the great military head quarters of the Madras presidency, and Ootacamund its sanitarium.

On this line the bridges again constitute the chief engineering difficulties. There are twelve principal rivers to cross; among which the largest are the Naggery, Cheyair, Paupugnee, Chittravutty, Penair, Hugry, and Toongahudra; the channel of the Cheyair being some 60 chains across, and the others varying from 10 to 40 chains, making an aggregate of bridging over these twelve rivers alone of more than 3 miles in length. The designs are principally for masonry piers, and superstructure of wrought-iron girders in spans of 60 feet, adapted for a single line of rails. The cuttings and embankments too, of the Madras railway are, it may be observed, all adapted for a single line, the masonry being constructed for a double line.

The total length of the north-west line, to its junction with that from Bombay, is 330 miles. Two ranges of hills are crossed; the first at Ballapilly, involving a heavy cutting through quartzite, and a gradient of 1 in 60. For about 130 miles the earthwork is tolerably heavy; but to the north of Cuddapah the great plains of black cotton soil prevail, and the earthwork will consequently be light.

The *Permanent Way*, between Madras and Arcot, 65 miles, is laid with

a double-headed rail, weighing 84 lbs. to the yard, in lengths of 20 feet. The rails are fish-jointed, and six sleepers are used to each rail length; the end sleepers being placed 1 foot 3 inches from the joint, and the others respectively 3 feet, 3 feet 9 inches, and 4 feet to the centre. The chairs, wooden trenails, and keys are all of the ordinary construction. West of Arcot, the line is laid with rails weighing 65 lbs. to the yard, which is considered sufficient for the requirements of the traffic. These rails are laid on seven sleepers to the same length of 20 feet. The gauge is 5 feet 6 inches. The expense of freight, from England to Madras, for the first portion of the line was very heavy, owing to all the materials being sent out during the Russian war, when vessels were obtained with more difficulty, and the charges were higher. This, together with the greater weight of the rails, has rendered the first portion more expensive than the rest of the line may be expected to be; although the greater distance to which the materials will have to be conveyed, as the works are extended into the interior, will add to the cost, as the line advances. The cost per mile of the materials landed at Madras was as follows:—

	£	s.	d.
528 rails, at 84 lbs. per yard = 132 tons, at £16 4*s.* 6*d.* per ton,	2,141	14	0
3,168 chairs, at 21¼ lbs. each = 30 tons 1 cwt. 8 lbs., at £8 5*s.* per ton,	247	18	10
6,336 trenails, at £6 7*s.* 7*d.* per 1000,	40	8	5
3,168 keys, at £6 9*s.* per 1000,	20	8	8
528 pairs of fishing-plates, at 28 lbs. per pair = 6 tons 12 cwt., at £16 per ton,	105	12	0
2,112 bolts and nuts = 1 ton 3 cwt. 2 qrs. 14 lbs., at £23 10*s.* per ton,	27	15	2
1,584 sleepers, at 6*s.* each,	475	4	0
	£3,059	1	1
Carriage—average of 65 miles, per mile,	60	0	0
Laying, including all labor and superintendence,	40	0	0
Total,	£3,159	1	1

At the commencement of the undertaking, tenders were invited in India, for the supply of chairs, fishing-plates, bolts and nuts; but the prices offered were, to use the words of the Government Consulting Engineer, so extravagant, as to furnish no ground for hope, that the Indian iron could compete with the English, or that the Indian railways could look for any considerable supply from local sources. The same officer

subsequently stated, as his opinion, that there was no reason why many, if not all, the materials required for the construction of the permanent way should not be made in India; but that, although much might be done hereafter, to the advantage of both parties, when the iron wanted is that merely consumed in the ordinary wear and tear of the works; and although it might be hoped, that castings of the nature of those required could be turned out at Porto Novo, cheaper than they could be brought from Europe, yet the means of the Indian establishments appear at present so limited, that only small and tardy supplies can be hoped for, and Europe must still continue to be looked to, for the chief supply of chairs for the construction of the line. These opinions are supported by the following facts. The East Indian Iron Company contracted for the supply of chairs, from their works at Porto Novo. These chairs were delivered at Madras at a cost of 72·8 rupees (£7 5*s.*) per ton, which was under the price of English chairs, as mentioned above; but about the same price, as that for which they were brought from England at a more favorable time. The casting of the Porto Novo chairs was found to be as good as the English; but unfortunately, the supply was very limited. The same Company, having recently established works in the vicinity of Salem, near the centre of the peninsula, have undertaken to supply 300 tons of chairs, at the rate 76¼ rupees (or £7 12*s.* 6*d.*) per ton, a somewhat higher price, but still a saving when the carriage from the coast, a distance of 200 miles, is considered.

The material for the supply of which the country can be depended on, is sleepers. Its forests and jungles afford a great variety of hard and durable woods, well adapted for the purpose. On the Madras Railway, twenty-eight different kinds of woods, have been used; which with few exceptions, have been found to answer well, when carefully selected. Much has been said of the damage anticipated from the white ants; but although few woods are not attacked by them, while lying exposed, and the sap wood, in particular, is much eaten away, yet in two years after the trains began to run on this railway, there was not a case known of a sleeper being attacked in the road. The vibration of the passing trains, and the frequent opening out of the ballast by the workmen, appear to be sufficient to prevent the attacks of this universally destructive insect. This will be better understood when it is known that the white ants never work but under a thin covering of earth, which they build over themselves; and this being shaken

off, their depredations cease until it has been renewed. Many woods are liable to the attacks of other insects, which bore holes into them; but the sleepers, when covered with ballast, appear to be free from these also.

Great numbers of creosoted fir sleepers were sent out from England, at a cost of 4¼ rupees (or 8*s.* 6*d.*) each at Madras, or about 4¾ rupees (9*s.* 6*d.*) each when conveyed fifty miles to the works; while the sleepers procured in the country vary in price from 2 rupees (4*s.*) to 3¼ rupees (6*s.* 6*d.*) each. These creosoted fir sleepers were found to be very durable. The wood itself is perishable in India, probably from the heat causing the turpentine, &c., to evaporate rapidly; but the creosote has the effect of preserving it, and of preventing the depredations of all kinds of insects, even when the wood is most exposed to their attacks. With reference to this class of sleeper it was stated, in a Report on the sleepers on the East Indian Railway, that some of a rectangular cross section were quite sound, after being laid for three years. It was also remarked, that the heat and the great drought have the effect of dissipating the volatile parts of the creosote, so that its peculiar odour is scarcely discernible, in sleepers that have been long exposed to the sun. From this cause, the sleepers of a triangular cross section, were found liable to split in the hot weather, the edges becoming dry and brittle. Various native woods were creosoted on the East Indian Railway, and the following statement, showing the cost of preparing four different kinds, is taken from the Report above referred to.

Description of wood.	Amount absorbed per cubic foot.	Contents of sleeper.	Total creosote absorbed.	Cost of creosote at 6½*d.* per gallon or 8 lbs.		Add for labor.	Total cost per sleeper.	
	lbs.	cubic ft.	lbs.	*s.*	*d.*	*d.*	*s.*	*d.*
Sál, ...	2	3½	7	0	5½	1	0	6½
Teak, ...	4	3½	14	0	11	1	1	0
Soondry, . . .	6	3½	21	1	4½	1	1	5½
Sissoo, . . .	9	3½	31½	2	0½	1	2	1½

This is exclusive of the original cost of the apparatus; but it includes fuel and attendance on the engine, together with all other labor and superintendence.

On the Madras Railway, a few thousand sleepers were kyanized, experimentally, with corrosive sublimate. This operation was effected by a

person who erected the apparatus at his own expense. The cost was about 4 annas (6*d.*) a cubic foot. The sleepers thus treated were all half round sál sleepers, in themselves very durable. After they had been laid for twelve months, there was no perceptible difference between the sleepers which had been kyanized, and those of the same wood, laid in the same place, but not so prepared; both being perfectly sound and good. It is worthy of remark, that a specimen sleeper, which had been kyanized, and kept in a covered verandah for about six months, had its sap wood bored by insects, in the same way as those which were unprepared. The great difficulty in the way of kyanizing, or otherwise preparing, any large quantity of sleepers in India, is the fact of their being received all along the line; involving the expense of collecting them, at certain points, for the purpose of being prepared. The same reason, however, does not exist to prevent sleepers being prepared for the *maintenance* of the way; as they can then be easily and expeditiously carried from the places where they are prepared, to the points where they are required.

In the neighbourhood of Arcot, granite blocks were obtained, measuring 2 feet square by 1 foot in thickness, at a cost of 1¼ rupee (2*s.* 6*d.*) each, and were made use of on some parts of the line, instead of sleepers. The cost of two blocks fixed was only about 6 annas (9*d.*) more than one sleeper fixed; but on account of the roughness and rigidity of the road, they were not used to any great extent. Near the coast, laterite abounds, and one mile of the line was laid with blocks of this material, as an experiment. It was found, however, that the blocks split, and their use was consequently abandoned. The price per block was 11 annas (1*s.* 4½*d.*).

A few native-made keys and trenails were used; but the former were not pressed, and although they answered well in wet weather, in the hot season they shrunk so much as to be unfit for use. The trenails, which are of teak, succeeded perfectly. A few lengths of rails were laid at one of the railway workshops, for the purpose of fitting up wagons to gauge. These rails have been laid for two years and a half, and, as might be expected, have not received much attention. Both the English elm keys and the oak trenails have, in the time mentioned, been riddled by insects. The trenails had not been driven home, but stood 2 inches, or 3 inches above the chairs, and the exposed parts had been attacked. This shows that, unless constantly watched, even English oak suffers in India. The insect alluded to is not the white ant, but a species of beetle, which, as

before stated, bores holes in wood left exposed, although covering up the wood with ballast seems to be a sufficient protection. It may be remarked, that the sleepers on which these rails were laid were of a native wood called "yengay"—botanical name, "*Acacia odoratissima*"—and although not covered by ballast, the sleepers were left untouched by the insects, while the oak trenails were almost entirely destroyed. In the curves of sidings, iron spikes were substituted for the wooden trenails, on account of the frequency of accidents from the trenails giving way.

In laying the road at first, the natives were found, as in almost every other kind of work, intelligent and apt, when care and patience were taken in their instruction. The gangs generally consisted of one mistry, or ganger, and twelve men; the pay of the former being about 6 annas (or 9*d.*) a day, and that of the men 2½ annas (or 3¾*d.*) each. In order to give the men some inducement to remain, the pay was increased, gradually, to 4 annas (6*d.*) a day, in proportion to the length of service. A day's work for a gang of the strength mentioned was usually twelve lengths of rails finished up. A European inspector had charge of four or five gangs. The cost of laying was, as above stated, about £40 per mile.

In the maintenance of the way and works the arrangements were as follows:—A Resident Engineer in charge of 72 miles; one European inspector to each length of 12 miles; one gang of workmen consisting of a mistry, or ganger, and seven men to each 1½ mile; one watchman to each mile; one timekeeper to every length of 6 miles; one paymaster to the division of 72 miles; and one storekeeper to the same length. Extra gangs were employed for ballasting and repairing any serious damage.

No. CLIV.

SAND PUMPS FOR WELL FOUNDATIONS.

A Description of the Sand Pumps employed in sinking the Well Foundations of the Bridge Piers on the Delhi Railway. BY CHARLES GENESTE, ESQ., C.E., *in charge of Sutlej Bridge Works.*

THE following pages contain an account of the "Sand Pump" from the first time it was used, in its primitive form, up to the present time, when, with the numerous alterations it has received, it is considered one of the most effective machines for sinking foundations in sandy soil.

In 1860, Mr. Howard Kennard took out a patent for the Sand Pump, or, as it was then called, "Sand Excavator;" and in the latter part of the same year, one was sent out to the Tagus Bridge, on the Lisbon and Badajoz Railway, where Mr. Kennard tried it, for the first time, himself. It then consisted [*Plate XL.*, *Fig.* 1] of a cast-iron cylinder, 3 feet diameter and 2 feet high; closed, top and bottom, with covers with air-tight joints; each cover having a circular hole in the centre about 6 inches diameter. Through the hole in the lower cover was a cast-iron pipe protruding for 2 or 3 inches below, and carried up, inside the box, to within 4 inches of the top cover. On the top cover was fixed the pumping apparatus; a bell-shaped leather bag 10 inches deep, the mouth being about 2 feet diameter and the top 6 inches; this was closed with an iron weight having a ring in the centre to which the pumping tackle was attached. Outside the bag, in the top cover, were several holes, closed with leather valves, for the discharge of the water. The body of the pump had iron lugs for lifting it, and a small wrought-iron door closing with a water-tight joint.

The principle was, that a vacuum should be formed by opening and shutting the leather bag when under water, thus causing the sand to come in with the water through the suction pipe. As the pump filled with sand, the water was discharged through the valves in the top cover, and when full it was lifted and the sand removed through the door; the sand being prevented from escaping, until the door is opened, by the inside pipe.

Mr. Kennard tried it in the bed of the river under a travelling crane; the pumping gear he worked by means of a single purchase crab, placed on the scaffolding which carried the traveller; the men turning and reversing the crab quickly, thus caused the leather bag to be extended and closed alternately. He worked it the whole of one afternoon, but without any marked success; the pump sometimes coming up half full, but generally with only 1 or 2 inches of sand in it. This pump was then put on one side and not used a second time.

Soon afterwards, Mr. Kennard sent out two more pumps [*Fig.* 2.] to the Tagus, slightly different to the first one. The leather bag, instead of being made bell-shaped, was cylindrical, about 10 inches diameter, with a heavy iron plate on the top, fitted with four valves working in the same way as those in the upper cover of the pump. The leather cylinder had also light iron rings sewn inside to cause it to close in folds. These pumps were sent out to the Tagus, but, Mr. Kennard having left, they were tried by the foreman, condemned, and laid on one side.

About the middle of 1861, the writer went out to Portugal for Messrs. Kennard with Mr. Wilson, who had charge of all the bridge work; and as the latter gentleman wished to see what could be done with the pumps lying useless at the Tagus, they were sent to the Mondego river, where the writer was about to commence a bridge.

The first time one was tried was on the 13th October, in a *six foot* cylinder, in about 4 feet of water. It was soon found that the iron plate on the top of the leather cylinder was not sufficiently heavy; so an extra hundred weight was put on, and it worked much better; at the first lift the pump coming up *one-third* full of sand. Owing to several stoppages this day, only six lifts were made, and the pier was sunk *one foot*, equal to 28 cubic feet of sand. The next day the pier was sunk *four feet*, equal to 112 feet of sand. A day or two afterwards, it was found that the rings inside the leather fell out, and so instead of closing in folds it fell over on the side, and of course did not work. To remedy this, a guide was

fitted to keep it straight. An iron bar [*Fig.* 3] with a hole in it, was put across the top of the suction pipe, and another across the opening in the top cover; there a long bolt worked through these holes, having one end connected with the iron plate on the top of the leather, and on the other end was a nut below the bar across the suction pipe.

This, on trial, was found to answer so far as keeping the arrangement straight was concerned, but it entirely destroyed the working powers of the pump; the bar being across the suction pipe, and the bolt working inside, evidently prevented the flow of sand. An outside guide [*Fig.* 4], was therefore fitted, which was found to work much better; but the next thing to be contended against, was the wear and tear of the leather, which, after a few days' work, was cut through, and of course rendered the pump useless until repaired. The final remedy for this was [*Fig.* 5] a piston for the leather cylinder. A cast-iron cylinder, about a foot long and 10 inches diameter, was bolted on to the top cover, and a leaden piston cast to work in this rather easily, having four holes in it, fitted with valves for the discharge of the water. In the centre of the piston a long bolt was fixed, about 2 feet long, having an eye on the upper end for the pumping tackle. This bolt passed through outside guides to keep it perfectly straight, and the piston had a leather belt round it, drawn in at the bottom and rather loose at the top, so that in the up-stroke the piston should be tight, and in the down stroke loose.

It was soon found, however, that this leather did not answer, the sand getting in between the leather and the lead, and so causing the piston to jam. It was then cut away, and in its place two iron rings were put, to take all the rubbing, but not fit too tight. With this the pumps worked very well, and from 6 to 12 feet a day could be counted on, according to the nature of the sand and the height of the lift. They would also work in shingle, but not so well, but in clay they could do nothing. The suction pipe was also found to work better with the lower part rather longer, and instead of 3 inches below the bottom, they were made 9 inches below. With these sand pumps, nearly all the foundations for the two large bridges over the Mondego were sunk by the writer.

In the latter part of 1862, the writer returned to England, and as he was then engaged on a railway without any large bridges, he lost sight of the sand pumps, and believes they were very little employed, until again brought into use on the Delhi Railway.

When the plant was ordered for this line by Mr. Henfrey (Messrs. Brassey, Withes and Henfrey, the contractors for the whole line,) the Sand Pump was mentioned as likely to be useful in the sandy beds of the Indian rivers, and, at the writer's suggestion, a number were sent out, together with steam hoists to lift them, the want of this having been felt in Portugal. In April last, the sinking of the piers was commenced at the Sutlej Bridge with both "Sand Pumps" and the "Jham;" and at the present moment, after ten months work, more than 1000 feet have been sunk; the sinking being about equally divided between the two: the sand pump during one day, of *seven* working hours, performing the extraordinary feat of sinking a pier, 12 feet 6 inches diameter, *six feet*, or excavating 736 *cubic feet of sand*, the pier at the time being about 36 feet in the ground. It also sunk 15 *feet in eighteen hours*, part of the time working in black clay and kunker.

Before, however, arriving at this state of proficiency, it was found necessary to make another improvement [*Fig.* 6] at the suggestion of Mr. Marellier, general Superintendent of the bridge work, which has almost doubled the working powers of the Sand Pump. This was the introduction of the removable bottoms, thus making the machine self-emptying, and allowing it to be kept continually at work with little or no delay. Formerly, the principal thing against them was the time lost in getting the sand out; the actual filling of the pump is merely a matter of about three minutes, and, by means of the steam hoist, it can be both lowered and lifted from the bottom in two minutes; but the emptying, although they were furnished with two doors, took about fifteen. This difficulty was partially got over by working two pumps on one pier with two trollies, one to take away the full one, and the other to bring up the empty one; however, naturally some time was lost in changing the lifting tackle, as each pump had to be disconnected every time. The greatest depth sunk with two pumps in one day was 3 feet 6 inches; and now, with the moveable bottoms, 4 feet 6 inches and 5 feet can be easily calculated on.

The pumps now are made without any doors, and the bottom, with the suction pipe, is made quite separate from the body, and held in its place by means of lugs fastened with colter pins. Each pump is fitted with two bottoms. When working, the pump is lowered to the bottom of the well, filled and lifted in a very short time; then one of the trollies, which work on a tramway, being run over the centre of the pier, receives the pump. The

colter pins are then knocked out and the lugs turned round, the steam hoist then lifts up the body of the pump, and the bottom is left in the trolly with its cargo of sand. This trolly is then pushed away on one side, and the other run under with the second bottom; this is fitted, the pump again lifted, trolly pushed away, and then the pump goes to the bottom and is filled a second time. When it is again lifted, the first bottom has been unloaded and ready to take its turn. Of course this is very hard work for the men, and they soon get tired; but when they are worked sharp for about an hour, one can actually *see* the pier sinking.

One other improvement [*Fig.* 7], I think, makes the Sand Pump perfect; this was applied to get over the difficulty encountered when coming on patches of clay or kunker. On the lower part of the moveable bottom, radiating cutters have been fixed made of plate iron, half-inch thick, sharpened and steeled at the edge; these are about 9 inches deep. When anything hard is met with, the pump is lifted about 4 feet, and is let fall again, several times, and by this means the clay, kunker, or whatever it may be, is generally broken up, and can be easily drawn into the pump. This last alteration has converted the "sand pump" into a "clay pump," and has enabled all the piers to be sunk 2 feet into the solid clay foundation. Up to the present time about 30 *feet* have been sunk in hard yellow clay, under a head of upwards of 40 feet of water, entirely with these pumps. This is in addition to beds of clay and kunker which have been passed through, some of them as much as 4 and 5 feet thick. The pumps will also lift bricks and stones (and have lifted many of 14 lbs. weight) if not too large for the suction pipe. Of course great care and judgment are required in the manufacture of them; every joint must be tight, and the piston must be a perfect fit, neither too tight nor too loose in the cylinder.

Plate XL. shows the different stages they have passed through, before arriving at the present form, and the writer has no doubt that now there is nothing so efficient and economical for sinking any foundations in sand. The original outlay is not large, and the cost of working small. Then the facility of transport and small preparation required for working them, are also great things in their favor: any depth of water is no drawback to them, in fact they work best in a depth where a *jham* would be perfectly useless, and nothing can sink a pier straighter on account of all the sand being removed from the centre of the well. In the writer's opinion, before

many years, the sand pump will be generally used, not only in India, but in England, and all over the world. Wherever there is sand, wells are now very generally used as foundation for bridges, and there is nothing more suitable for sinking them than "The Improved Sand Pump."

C. G.

Note by Editor.

I had the pleasure of seeing the Sand Pumps working in January last, at the Jumna and Markunda Bridge Works, on the Dehli Railway; the 12½ feet wells being then sunk 40 feet through sand, with an intervening stratum of clay, 6 feet thick at 16 feet from the surface: and have nohesitation in saying that it is one of the most admirable inventions ever applied to Indian Engineering. Even without the more expensive aid of the steam hoist, and lifted by coolies with a chain and block, working on the *gallows* shown in *Plate XLII.*, there can be no question of its superiority over the jham, and every engineer who has such work on hand will do well to provide himself with the apparatus, when procurable.

The cost of the pumps in England is £25, exclusive of the patentee's royalty. The invention has been, I understand, protected in this country, and at present Messrs. Brassey and Co., enjoy the exclusive right of using it in India. It is probable, however, that in another month or two arrangements will be made for supplying other parties on fair terms. The price of the Steam Hoist as used on the Delhi Railway is £270—it is of 4 horse-power and is manufactured by Messrs. Jas. Taylor and Co., of Birkenhead.

No. CLV.

REWAREE SLATE QUARRIES.

Account of the Slate Quarries in the Goorgaon District. BY CRAWFORD CAMPBELL, *Esq., Executive Engineer, Delhi.*

IN accordance with the verbal instructions of the Chief Engineer, I proceeded in January last to visit the slate quarries near Rewaree, in the Goorgaon district.

My route thither was a circuitous one, as business led me first to Noh and Malubbut; this deviation from the direct road enabled me to examine carefully the geology of the district, and from the information thus procured, and from notes made in previous years, I have compiled the accompanying Sketch Map of the Lithology of the Delhi and Goorgaon districts. I wish I could have expanded this into a regular geological map of the whole system; of the fringe (or edge) to which they form merely a small portion; but time was wanting for even the most cursory examination of the Ulwur, Narnoul, and Dadree Hills; a survey of which would doubtless be productive of very beneficial results, as a reference to the notes on the sketch will show.

The rocks in the districts under notice are wholly metamorphic; and form two distinct masses, of which the Sahabee nullah may be taken as the dividing line. The easternmost is of gneiss in large broad masses, forming a continuous ridge from Meolee to Delhi, where it dies out under the waters of the Jumna, and does not again appear. The more western of the two consists of detached hills, projecting above a sandy plain; which become fewer in number and smaller in size as they approach the

great desert, and cease, rather than die out, on the southernmost boundary of Hurreana and Bhuttiana. These hills, as far as I have examined them, are wholly and purely clay slate.

The strata composing them dip to the north; the strike lying nearly due east and west; whilst the lines of cleavage run pretty uniformly in a direction N. 14° E., and are generally inclined to the horizon at an angle varying from 48° to 76°. In some few places they are quite perpendicular, and at the top of the Palee hill, I found the uppermost bed curved over, from what cause it is difficult to say; but certainly not from either of those to which similar phenomena are generally attributed in the slate quarries at home. The quality varies much, and but little of it is fit for roofing purposes. In most of the hills the cleavage plains are wide apart, and the slate becomes a mere argillaceous flagstone, more or less hard and compact. In this condition it is used as rubble in masonry walls, and forms a capital building stone. For lintels, the natives use Kirwanee stone, a mica schist, from a place in the Ulwur territory, lying 25 miles south-west of Rewaree. I mention this to show that the clay slate passes into mica schist as it approaches the hills of Mewat.

My examination of the slate hills was necessarily a very superficial one; but I only noticed three places where good roofing slate is likely to be obtained—they are Palee, Manetee, and a small hill, three miles east of Rewaree. At Palee there is a ridge about one mile long, with three crests reaching to a height of from 300 to 450 feet above the plain. At the very summit are a few places from which roofing slate is sometimes extracted; but, unfortunately, the quality rapidly deteriorates lower down the hill, until at the bottom it becomes unfit for anything but building purposes. This is clearly seen, as a quarry was opened here, some 80 years ago by the then Raja of Rewaree, who took hence the stone used in the construction of the famous tank in that city. Even in the uppermost layers the beds are very irregular, and there are a good many veins of quartz: in fact but little good roofing slate could be got, and it would be useless opening any regular quarry here.

In extracting the slate, the natives use only the wedge and hammer; they never resort to blasting, and pick out purposely the softest stone where the cleavage is the coarsest. In fact they appear to consider hardness and tenuity a positive disadvantage, and do not care to get out anything under half an inch in thickness.

Three miles from Palee are the quarries belonging to the village of Manetee, whence have been procured the roofing slates used in the Goorgaon and Rewaree school-houses. They lie at the southern extremity of the Khóle hill, a large and imposing mass covering some square miles of ground, the highest peaks of which rise about 1,000 feet above the plain, and are over 2,000 feet above the level of the sea. The site of the quarries is however a low flat plateau, barely rising above the plain, about half a mile long by half that width. The cleavage plains and beds are regular and well defined; the slate is of good quality and color, and there are no veins of quartz and fewer foreign substances in the slates itself than is the case at Palee. In fact, we have here a capital site for a quarry, and if the upper beds were blasted away, slate equal to any in Wales could be procured.

I should state that the quality of the Manetee slate cannot be judged from the specimens sent to Goorgaon and Rewaree. These latter have been taken from the softest beds about, which were evidently selected by the natives as being the easiest to work. They are deficient in hardness and tenuity, are of a very bad color, and will never form a good lasting roof.

There is a smaller hill to the south, and in continuation of the one containing the Manetee quarry, from which it is only separated by a narrow nullah. The slate is of good quality, but the beds are much thrown and distorted, and the cleavage plains are irregular and highly inclined from the perpendicular. I could not detect any likely place for a quarry here.

The nearest point to Delhi at which the slate protrudes above the plain, is about three miles east of Rewaree, close to the Patondie road, where there is a mass of rock about 100 yards long and 30 feet high, on the top of which stand a mosque and two tombs. It appears to be considered a sacred place, so that there might be some difficulty in quarrying here; but this is of less moment, as, although the slate is hard and of a good color, there is but little of it, and the bedding and cleavage are very irregular.

The only other place in the Goorgaon district where good roofing slate is found, is said to be a hill at Papree, near Pentungwa. I was unable to visit it, but it is described to me by competent eye-witnesses as closely resembling the Manetee quarry, a long low reef of slate, where the natives pick out the softest places and extract what they require with coarse wedges and hammers. Judging by the specimens sent in to me, the quality of the slate is inferior to that of the Rewaree system.

From what I have said, it will be seen that true clay slate is to be found in these districts, and that it can be readily made available for roofing purposes in the Delhi division. It will also be gathered that the quarries at Manetee give the fairest promise of good material. They are, besides, much more accessible than those at Papree, or than any other unexplored ones that may hereafter come to light; for they are only 13 miles from the projected railway *viâ* Rewaree to Rajpootana. I therefore beg to recommend that measures be taken to open them out in a systematic manner. For this purpose English supervision should be largely employed. Blasting must be resorted to, and proper tools for dressing and splitting the slate will have to be introduced. All this will cost money, and the slate will at first be an expensive article compared with the terraced roofs now in use; but its lasting qualities and other excellencies as a roofing material will, I believe, more than compensate for this disadvantage.

C. C.

No. CLVI.

POONA WATER-WORKS.

Project for the Water Supply of Poona and Kirkee. Abridged from a Report by Lieut.-Col. Fife, R.E., *Superintending Engineer.*

The supply of water to Poona has always been a difficulty; and in 1848 the Jamsetjee Bund, across the River Moolla Moota, was constructed, and machinery erected for pumping what was then considered a sufficient quantity of water up to the Cantonment. How very imperfectly this work has supplied the deficiency is well known to Government and all residents at Poona, and the lucid report of the 5th September, 1865, by Dr. Leith, the President of the Sanatory Commission, has most completely proved the utter hopelessness of our ever obtaining a supply of pure water from that source.

The cantonment of Kirkee has recently been shown by Dr. Leith to be actually, if possible, in a worse position than Poona as respects good water, but less has been heard of the hardship, from the station being so much smaller.

The supply of water to the City of Poona has also always been defective, and though the proverbial public spirit of wealthy natives in constructing wells and conduits has done almost everything that could be done, a very large portion of the population is still dependent on the river for water, and as the stream ceases to flow in February, the people take the water from stagnant pools or pits excavated in the bed. The water obtained from the latter would be pure in any open part of the river, but at the City, where both banks are crowded with houses, and every sort of filth finds its way

down to the river bed, the water cannot be pure; and the quantity is moreover very small, as the Moota, like most of the Deccan rivers, has rock close under the bed, and in places the bed itself is rock. During a drought which occurred about 30 years ago, the people were reduced to such a condition of distress that they excavated a cut in the river bed to tap some pools situated about 12 miles off. During the past season an attempt was made by the Public Works Department to bring water down to the city in the same way, and it was of some use.

The City of Poona has not enough water for ordinary purposes; much less does the supply suffice for sewage, for which, practically speaking, there is none at all except during heavy rain. Government has already been made acquainted with the condition of the sewers from a report dated 8th August, 1865, submitted by a Committee composed of Dr. Leith, Mr. Duff the Collector, and myself. It was found by the Committee that the present sewers were choked up from the proportion of solid matter finding its way into them being too great, and that they were in fact nothing more than elongated cesspools, polluting the ground in every direction. To improve the sewage was simply impossible without a copious supply of water, such as is afforded to European cities.

No project was ever prepared for affording Poona an adequate supply of wholesome water, but it is probable that the city, with a population of 70,000, will require as much water as the Cantonment, or 1,500,000 gallons a day.

Briefly summarizing the history of the question of the water supply of Poona and Kirkee, and of the City of Poona, it appears; 1st, That the supply of wholesome water has always been inadequate, and that the increasing population, with the location of the Powder Works and Arsenal at Kirkee has rendered it now imperative that water-works should be at once undertaken.

2nd. That the cost of affording an adequate supply on the small tank and pipe system will be as follows:—

	RS.
Poona Cantonment—1,500,000 gallons per day, ..	14,17,840
Kirkee Cantonment and Powder Works—934,665 gallons per day, ...	6,91,339
Poona City—1,500,000 gallons per day, ...	7,19,846
Total probable cost, ..	28,29,025

3rd. That the water which will be obtained will be of inferior quality in the hot season, when the reservoirs sink to a low level.

The project I am now about to describe will not be quite new to Government, nor, I may add, is it really new at all as far as the source of supply goes, but it is on a larger scale than the projects formerly brought forward, and it is principally owing to this increase in size, that after the most careful investigation of the whole question, I have been led to revert to a source of supply that was formerly rejected. This source of supply is the river Moota itself, but at a distance of 11 miles above Poona, a locality thought of so far back as 1855, and strongly urged by the late Hon'ble Mr. Reeves as most suitable for the purpose.

The feasibility of obtaining water from the Moota was considered by Captain Hart in his investigation of the water supply for Poona Cantonment, but the plan was rejected by him in consequence of the want of slope that would be available for the pipe from the river to Poona. For a project to afford the comparatively small quantity of water then contemplated, Captain Hart was right in his conclusion, but the question has now assumed a different aspect. What Captain Hart had to decide was the best means of obtaining 821,917 gallons a day: what has now to be decided is the best means of obtaining 3,000,000 gallons per day, with a demand for much more, (if it can be furnished,) for garden irrigation in the vicinity of Poona, where the extensive European and Native population creates a large demand, I may even say a necessity, for garden produce. Under this altered aspect of the question, it appears that our best plan will be to revert to the Moota river as a source of supply, to form one large reservoir upon it, and to lead the very large quantity of water required by open ducts (for which the available slope is sufficient), to expense reservoirs in the vicinity of Poona and Kirkee, whence iron pipes will distribute the water for the various purposes for which it is required. The advantages of this plan are the greater facilities for storing and conveying a large supply of water, and consequently greater economy; and the greater purity of the water obtained from a reservoir, which, it will be hereafter explained, is never to be less than 50 feet deep opposite the reservoir dam. With these prefatory remarks I may now proceed to a description of the project.

The Reservoir.—The site selected for the reservoir is immediately above the village of Kurrukwasla, where the slope of the valley, 6 feet per mile, and the rocky nature of the ground, afford the requisite facilities for obtaining a large capacity for the reservoir, and perfect security from accident for the masonry impounding dam and the waste weir.

From the level of the stream being rather low at this point, and from the necessity for making allowance for silt deposit, as well as to avoid the necessity of completely draining the reservoir to obtain the whole quantity of water required, the feeding level to the ducts which have to lead the water to Kirkee and Poona has been fixed at 65 feet above the lowest part of the bed of the river, and about 40 feet above the banks. At this level the area of the reservoir will be 3 square miles.

The loss by evaporation in this large reservoir during six months, after which replenishment will take place from the showers at the commencement of the monsoon, has been taken at 5 feet perpendicular; and to provide for the whole quantity of water, 715,392,000 cubic feet, to be furnished during the 6 months of perfectly dry weather, the dam is to be 20 feet above the level of the feeding point. The area of the lake at this level will be $5\frac{1}{4}$ square miles. Its average width will be two-thirds of a mile, its average depth 36 feet, and it will be $7\frac{1}{2}$ miles in length.

The Dam will thus be 85 feet high at the deepest part of the valley, or where it crosses the river. Only 400 feet in length will however be of this height. The remainder varies from 60 feet at the bank of the river to almost nothing where the dam is connected with the hills on both sides of the valley. The dam is to be of masonry, and, to check leakage, a bank of earth will be added to its base on both sides. It will be founded on rock throughout its whole length, and is of such a massive construction as to entirely set at rest any fear of such a catastrophe as occurred at Sheffield. The masonry dam, as will be seen from the calculations given in Appendix A., is in excess of what is required to resist the pressure of the water when the reservoir is filled up to the highest possible level, or when there is a stream 5 feet deep running over the waste weir. The total length of the dam is 2,900 feet, and the average height 48 feet.

The Waste Weir.—The waste weir is one of the most important portions of every water supply project, and in the present case, when the works are to be on a large scale, more than ordinary care and attention have been bestowed upon it. The heaviest flood which has been observed during the past two years, during which the state of the river has been daily gauged and registered, amounted to 45,405 cubic feet per second; but from reliable information obtained from the villagers of Koprah, whose village stands on the bank, it has been found that during an extraordinary flood which occurred in 1861, the river rose 6 feet higher than our gauge has indicated during

the past two years. The flood discharge on that extraordinary occasion has been carefully calculated, and amounts to 82,079 cubic feet per second. The waste weir has been designed to discharge this volume. It is true that with the large reservoir the effect of a flood must be modified, and that instead of rushing past Koprah with a discharge of 82,079 cubic feet per second, and lasting at that height only an hour or so, it will raise the level of the water in the reservoir gradually, and escape by the waste weir in a smaller quantity per second, but will last many hours. Still, to be on the safe side in this important matter, it is better to give the waste weir dimensions, which will enable it to discharge the greatest flood that has ever been known to occur with the river in its present unobstructed state.

The waste weir provides for the escape of 82,079 feet per second, and the control of so large a stream as this has been very carefully studied. We have not been contented by an appearance of rock where the overfall will occur, but have actually blasted portions away at intervals all along the site to be quite sure that the rock is really solid and sound, and not a mere superficial covering to some softer stratum below. A defect in the rock would certainly not cause a catastrophe, but it would cause a leak, which would allow the water to be wasted in the first instance, and it would afterwards lead to a great deal of trouble and expense for repairs. I am glad to say, however, the result of the examination of the rock has proved satisfactory. After removing from one to five feet of the surface it has proved perfectly sound, and the bed extends from the waste weir site to a nullah in rear, and thence to the river bed again, at a distance of 1,200 feet below the dam. The nullah forms the depression by which the waste water will find its way back to the river again. The water is prevented from spreading towards the dam by means of a massive wing wall as strong in construction as the dam itself. The waste weir has an average height of 9 feet, and is 1,660 feet long. The water will flow 5 feet deep over its crest during the heaviest floods. Calculations for this work will be found in page 280.

The Ducts.—For Kirkee the ducts will have a slope of one foot per mile, a bottom width of 5 feet, depth 2½ feet, velocity of current 1·4745 feet, and the theoretical discharge of 32·2775 cubic feet per second. This duct will supply 26 cubic feet per second for the irrigation of 4,000 acres of land, and 1·75 cubic feet per second, or 934,665 gallons per day for Kirkee, the quantity fixed by Government Resolution, of the 10th August, 1865.

The duct will be of uniform size, that a week's supply for Kirkee may be carried in a few hours to the expense reservoir in order that the water may not sustain injury from passing in a slender stream along an open channel. The length of the duct will be 16 miles, as the unevenness of the ground makes the route circuitous. At that distance from the head works, settling and expense reservoirs are provided on the high ground opposite to Kirkee hill, with a command of 37·08 feet over the European Barracks, and 25·72 feet over the highest delivery point in the Powder Works on Kirkee Hill. The water will be conducted from the reservoir by means of an iron pipe, varying from 14 inches in diameter in the portion from the reservoir to the barracks, to 12 inches in diameter at the delivery point at the Powder Works. Smaller branch pipes distribute the water from the main pipe. The main pipe passes over the ground which will be occupied by the proposed Fort.

There is nothing in the nature of the works on this duct which demands any great explanation. All drainage is passed under the duct by aqueducts and culverts, in exactly the same manner as in the irrigation works constructed in Khandeish. The water will be admitted into the duct from the reservoir by a simple sluice, the head of water to contend with being only 12 feet. The settling and expense reservoirs on the hill opposite Kirkee will contain one week's supply, and are formed in a small depression close to the watershed. The water is retained on the low side by a masonry wall backed with earth, and the bed of the reservoirs will be rock, all the overlying soil being scraped away.

On the Poona side of the river less fall is available than on the Kirkee side, and the slope of the duct is therefore only 6 inches per mile. The bottom width will be 10 feet, the depth 3 feet, the velocity 1·2023 feet per second, and the theoretical discharge 52·30 cubic feet per second. This discharge provides for 2·75 cubic feet per second, or 1,500,000 gallons per day for Poona Cantonment (the quantity fixed by Dr. Leith), 1,500,000 gallons per day for Poona City, and for 2,000 acres of irrigation. As in the Kirkee duct, there is no diminution of section towards the tail, and for the same reason, viz., that the water may be run off from the great reservoir to the expense reservoirs for Poona Cantonment and city, in a few hours.

The Poona duct will be altogether 11½ miles in length. At the 9th mile it passes the Parbuttee Tank, which it commands. This tank is in-

variably dry when there is a great scarcity of water, but may now be used as an expense reservoir by the Municipality of Poona. It is unnecessarily large, but a portion may be easily shut off so as to form a reservoir of the requisite size. The Parbuttee Tank commands the whole of the city, hence the distribution of the water throughout the city by means of pipes will be a matter of no difficulty.

At the 11½ mile, or termination of the duct, two quarries now used as tanks, and situated near St. Mary's Church, are entered. The first one will have a retaining wall, averaging 5 feet in height built round it, and will be used as a settling reservoir. The second will have its lower edge raised 6 feet by a masonry wall, and it will then hold a week's supply of water for the Cantonment. The water will be distributed from this reservoir to the Bazar, Native Infantry Lines, Civil Lines, and Ghorepooree, by iron pipes and gravitation. For the Wanowree Lines, now occupied by H. M.'s 33rd Regiment, the water, if distributed through the Barracks, must be raised by machinery, and this is provided in the estimate. The quantity of water to be raised is 300,000 gallons per day, and the cost of raising it 90 feet, capitalized, is Rs. 85,600.

There is nothing in these works which demands any particular explanation. The drainage will all be passed under the duct. Fencing is provided for both sides of the duct when it gets near Poona, that people may be prevented from drawing water directly from it. At the expense reservoir, side chambers are provided for the people to draw water from, that there may be no necessity for taking water direct from the reservoir. All natural drainage will be excluded from the reservoirs.

The cost of the works for the whole project will be as follows :—

	RS.	A.	P.
Main reservoir dam with waste weir and sluices, ..	9,52,121	14	9
Kirkee open duct, ...	78,458	6	4
„ settling and expense reservoirs, ...	16,642	3	1
„ main pipe, ...	1,06,831	8	4
„ distribution pipes in Powder Works, ...	56,277	0	0
„ distribution pipes for Cantonment, ...	24,795	0	0
Poona open duct,..	1,22,000	2	2
„ settling and expense reservoirs, ...	23,887	8	0
„ cisterns, ...	41,646	0	0
„ main pipe, ...	32,358	14	4
„ distribution pipes by gravitation, ...	79,129	13	8
„ steam power for raising water,..	94,600	0	0
„ distribution pipe for Wanowree Lines, ..	24,301	4	0
Total, ...	16,53,049	10	8

This estimate, it will be observed, provides for both supplying and *distributing* the water in the most complete manner; but as our present position is one of absolute want of water, it would be a great boon merely to have the water brought into Poona and Kirkee to central reservoirs, whence it might be conveyed by carts and bullocks as at present practised from wells, leaving the more perfect distributing arrangements to be carried out afterwards, as rapidly as funds may be available. The distribution through the Powder Works is however essential immediately, as also a pipe to lead the water from the central reservoir in Poona to the Ghorepooree Lines. The remainder may be easily deferred. If, therefore, Government should prefer for the present simply to obtain an abundant supply of good water, which will be at least within reach of all the inhabitants, but not distributed in detail except to the Powder Works and Ghorepooree Lines, the estimate will become as follows:—

	RS.	A.	P.
Main reservoir dam, with waste weir and sluices, ..	9,52,121	14	9
Kirkee open duct, ...	78,458	6	4
„ settling and expense reservoirs, ...	16,642	3	1
„ main pipe, ...	1,06,831	8	4
„ distribution pipes to Powder Works, ...	56,277	0	0
Poona open duct, ...	1,22,000	2	2
„ settling and expense reservoirs, ...	23,887	8	0
„ pipe to Ghorepooree lines, ...	10,673	4	0
Total, ...	13,66,891	14	8

The distribution of the water afterwards throughout the Bazar, Civil Lines, and environs of Poona might be carried out with the aid of Bazar and Municipal Funds, and a cess on houses, which owners would be quite willing enough to pay, for property beyond Municipal limits.

The cost of supplying the troops and Government Departments with water, according to a statement received from the Quarter-Master General of the Army, and other data obtained from the Public Works Department, is Rs. 36,130 per annum, taking the average of the three past years. This average, however, is not a fair criterion, because the increasing expense during the latter year is in a great measure owing to the rise in the rate of hire for bullocks, &c. To guide us, therefore, with respect to future expenses, supposing delay should occur in constructing water works, it would be more correct to take the expense of the last year shown in the statement. This expense may be divided under two

heads; the cost of supply, which comprises the expense of pumping the water from the Jamsetjee Bund, and its maintenance; and the cost of conveying the water by bullocks and carts from the river or wells and the central reservoir near the Pcona Arsenal to the troops and Departments. Dividing the expense in this manner we find that the cost of supply is Rs. 11,750, and of distribution Rs. 29,544.

It is not easy to say what the cost to private individuals is for bheestees, but from what I have learnt from the Bazar Master at Poona of the number of bheestees in the Cantonment, I feel sure I am understating the expense when I set it down at Rs. 60,000 per annum. Much of the annual cost of distribution is caused from the great distance the bheestees have at present to carry the water, and the time they lose in drawing it from deep wells, where they have not only the labor of hauling the water up, but are also kept waiting by the crowds of people who congregate to obtain their daily supply of the precious fluid. Government is no doubt aware that it is only by placing guards over the wells that the Brigade authorities can manage the distribution of the small quantity of water obtainable.

If the water-works now under consideration be carried out without the most perfect distributing apparatus, the expense of distribution by the ordinary means will still be greatly reduced. There would be no occasion to have recourse to the river at Kirkee. Water would be obtainable within a few yards of the Barracks and Horse Lines. At Poona the facilities would be similarly increased. Bheestees, instead of having to wander about from well to well, and carry the water a mile to its destination, would obtain it at the central reservoir at St. Mary's Church, at a point near the Arsenal, where the pipe to Ghorepooree will pass, and within a few yards of Ghorepooree Barracks. The expense of distribution will certainly be reduced to one-fourth of what it costs just now. Government would thus be saved—

		RS.
1st.	The cost of supplying water, ...	11,750
2nd.	Three-fourths of cost of present distribution (Rs. 29,544), ...	22,158
	Total Rs., ..	33,908
The public would be saved three-fourths of Rs. 60,000, or,		45,000
	Total Rs., ..	78,908

Should the project now submitted be approved, I would strongly urge an immediate commencement of the dam at Kurrukwasla, that the foundations may be got in and the work raised about 20 feet, before the monsoon floods commence, otherwise a whole year will be lost, as it is only between the present time of the year and April, that impounding works can be commenced. If commenced early, the dam could be brought up to a height of 20 feet during the present season. During the following season it could be brought up to the level of the site of the waste weir, the foundation of the waste weir only being put in, to give the water a free escape at a low level. By February 1868, or in two years and three months from the present time, the works could be completed to their full height, and as the reservoir would be filled by the monsoon of 1867 and the stream which continues to flow after the monsoon is past, the water supply works, except for irrigation, could be in full operation from December 1867, or even earlier, as the surface of the reservoir would be above the feeding level of the ducts. As another reason for recommending the immediate commencement of the works, I should mention that my assistant, Lieutenant Buckle, R.E., who has been engaged on the project during the past year, and who is fully acquainted with all my views and the whole of the details of the plans, is now on the spot, and Government is well aware of the great advantage of employing an officer to carry out a large work who has been engaged in the preparation of the plans.

Specification.

The works are to consist of a dam across the river Moota to form a reservoir, two open ducts to lead the water thence to settling and expense reservoirs at Poona and Kirkee; and iron pipes to distribute the water throughout the Cantonments and Powder Works, as also a horse-power engine to raise the water for a small portion of the Poona Cantonment, viz., the Wanowree Barracks. The general description of the arrangements is given in a more complete manner in the transmitting report on the Works.

Detailed Description of Dam, Waste Weir, and Wing Wall.—The dam, waste weir, and wing wall will be founded on rock throughout the whole length. The dam, which is to be of masonry, is to have a section in which the base = ·55 of the height, measured up to the highest water line; the thickness at top = $\frac{1}{4}$th of the base. Batter on water face = $\frac{1}{20}$th of height. Batter in rear to be $\frac{4}{11}$ths of height.

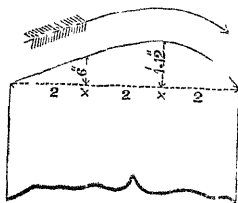
The dam to be raised 3 feet above highest water line, or 8 feet above the crest of waste weir, and to be surmounted by a parapet wall 2 feet thick and 3 feet high. This section will give a top thickness to the dam of 10·56 feet where it is highest in the centre of the valley. Where the height of the dam is much less, and where the proportion given would reduce the total thickness to less than 4 feet, the section to be modified by omitting the batters first on the water face, and then on the rear face, so that the top thickness may never be less than 4 feet The dam will thus become rectangular in section where it is very low, and the mass of masonry will be unnecessarily heavy; but this cannot be avoided, as 4 feet must be regarded as a minimum for the top thickness.

At the south end of the dam, four small sluice openings to be constructed, with valves working vertically against the water face. The sluice openings to be 3 feet wide and 3 feet high, and arched over. At the north end of the waste weir three similar sluices to be constructed to supply the Kirkee duct. The sills of the sluices to correspond in level with the bottoms of the ducts. The sluices to be worked from above by rack and pinion action. When the water is escaping over the waste weir, the sluices in the waste weir may be closed, as the duct will then receive its supply from the waste water. To prevent the waste water flooding the Kirkee duct, a stop gate to be constructed where the duct enters a cutting after getting clear of the waste weir channel.

The wing wall where the dam terminates and where the waste weir begins, to have precisely the same section as the dam itself; that is, in proportion to the head of water it has to sustain, but with minimum top thickness of 3 feet.

The dam and wing wall, though founded on rock, might still not prevent leakage through the rock, supposing any cavities to exist in the rock, and to prevent this, and staunch the water as completely as possible, good puddling earth to be added to both sides of the dam to one-third its height, *vide* sections of dam. The slope of the earthen banks to be one in two, horizontal, where the dam crosses the river bed; all the gravel overlying the rock to be carefully removed before the puddling earth is laid down. The wing wall to have a similar bank of earth, but on its rear side only.

The waste weir to have a stronger section than the dam, as it will be exposed to more severe action. Its thickness to be equal to one-half the

height; to be perpendicular on the down-stream face, and with a batter of one-sixth of the height on the up-stream face. Where these proportions would reduce the top thickness at the low end to less than 4 feet, the batter to be omitted, and the section made rectangular, that the top thickness may not be less than 4 feet. The top to be slightly rounded. *See* diagram.

Specification of Dam, Waste Weir, and Wing Wall.—The unwatering of the foundations at the deep part of the dam will be best effected by forming a small cut about 10 feet wide through the gravel, from the dam site to the nearest pool, which is at a distance of about 500 feet, and forming a similar cut at the lower end of the pool at a distance of one mile from the site. The water level may thus be lowered, till the rock, on which the dam is to be built, is laid dry.

The whole of the masonry at the dam, wing wall, and waste weir, to be of common coursed rubble, with the exception of the water faces of the dam, wing wall, and waste weir, which are to be of closer jointed work. The joints, however, are not to be fine in the dam, otherwise there will be unequal settlement in the face and body of the work. Half-inch joints will be quite close enough, and the stones should be only hammer-dressed The wing wall water face should be the same as the dam to within 50 feet of where it joins the waste weir, where the face work should be the same as that of the waste weir. The waste weir's down-stream face and coping to be close jointed work, the joints being one-quarter of an inch only. The coping to be made of stones not less than $1\frac{1}{3}$ feet by 9 inches; the top to be roughly chisel-dressed; the stones on the down-stream face of the waste weir, though close jointed, need not have their faces dressed off with the chisel.

The sluice openings to be of the best close quarter-inch jointed work, and the stones dressed smooth on the face, that the stream may not be impeded; the stones used for the grooves to be not less than 2 feet × 1 foot 9 inches. The valve or shutter to be of teak wood. The parapet wall on the dam to be of ordinary coursed rubble masonry, with rounded coping, close jointed, but surface unchiselled; the top of the dam to be roughly hammer-dressed.

The lime used for all the work to be hydraulic. Nearly all the Deccan

lime is naturally hydraulic, but that used for these important works must be carefully tested, to prevent ordinary lime being used. The stone to be of durable quality, and quarried close to the works. Very large stones, just as they come from the quarry, may be used for the body of the dam, waste weir, and wing wall, but the greatest care must be taken to fill in all interstices between them with smaller stones, chips and mortar. As far as the shape of the stones is concerned, the very coarsest work will suffice, provided all the interstices are carefully filled in, so as to make the work really solid and water-tight.

In procuring puddling earth for the slopes on both sides of the dam no excavations are to be formed anywhere in rear of the dam, and not within 200 feet of it in front. The material must be taken at a distance exceeding 200 feet in front of, and immediately below, the waste weir.

The Ducts.—The ducts will be generally entirely excavated, as they are too small in section to admit of half cutting and half embanking to answer. The excavated material will be nearly all required to shut out local surface drainage from the fields on both sides, but principally on the high side.

The sections of the ducts to be as follows:—

Kirkee Duct.—Fall 1 foot per mile; bottom width 5 feet; depth $2\frac{1}{2}$ feet; the slopes 1 in $1\frac{1}{2}$; theoretical velocity and discharge 1·4745 feet per second, and 32·2775 cubic feet per second.

Poona Duct.—Fall per mile 6 inches; bottom width 10 feet; depth 3 feet; side slopes 1 in $1\frac{1}{2}$; theoretical velocity and discharge 1·2023 and 52·30 cubic feet per second, respectively. All drainage is to be passed underneath the ducts by means of aqueducts, culverts, and syphon culverts; and all aqueducts standing on a rock formation to have their parapet walls made lower in the centre than at the wings, that they may serve as escapes should too much water ever get into the ducts. At the head of the Poona duct a retaining wall to be carried along the lower side of the duct, rising to 3 feet above water level, as far as Kurrukwasla, to prevent injury to the head-works, supposing anything should get out of order with the sluices, and more water enter the duct than it could carry off. Beyond Kurrukwasla the surplus water would find a ready and safe escape back to the river again by means of the nullah on which No. 1 aqueduct will be constructed. Retaining wall to have a bank of earth against it, and to have a thickness one-fourth of height, and to be founded on rock or hard moorum. At the

head of the Kirkee duct, the lower side of the duct, where it will cross the waste weir channel, for a short distance to be retained by a masonry wall having a thickness = one-half its height, but the minimum thickness to be not less than 2 feet; and where it is attached to the waste weir, and for a distance of 60 feet, its top thickness to be not less than 4 feet, as it will be subjected to a very severe action here from the waste weir overfall.

Specification for Aqueducts, Culverts, and Road Bridges.—Foundations and superstructure to be of the commonest coursed rubble, with all interstices between carefully filled with chips and good mortar, that the wall may be solid and water tight. Copings to parapets to be of dressed stone. All aqueducts standing on a hard foundation to have the parapets lower in the centre (equal to full supply level of duct) than at wings, that they may act as escapes.

The four Poona Road Bridges, for the Sunkersett Road, to have the superstructure and parapets of good coursed rubble, and coping of close jointed work, to be in keeping with other road bridges about Poona. On the Kirkee duct the road bridge for the old Bombay Road is to have masonry of the same character. The backs of aqueduct arches to be covered with 6 inches of concrete, with surface well finished off to prevent leakage.

J. F.

Calculations showing the Stability of the Masonry dam across the River Moota.

Extreme depth or head of water, during heaviest flood, 85 feet.
Height of dam, without parapet, 88 feet.
Thickness at base = 0·55 of head of water.
Thickness at highest water or flood level = 0·25 of thickness at base.
Batter on water face = $\frac{1}{20}$th of height.
Batter on rear face = $\frac{4}{11}$ths of height.
Weight of one cubic foot of water = 62·32 lbs.
Weight of one cubic foot of masonry = 150 lbs.

First, to find the centre of gravity of the figure.

The centre of gravity of the paralellogram ABEC is at P its centre, and 44 feet, or half the whole height, from the base.

The centre of gravity of the triangle BED is at Q, which is one-third of the whole height, or 29·33 feet from the base.

Join PQ, and through Q draw the horizontal line HQ; from P let fall the perpendicular PF to meet HQ in F.

Then to fix the position of O, the centre of gravity of the whole mass of masonry, we have—

$$PO \times ABEC = QO \times BED$$
$$= (PQ - PO)\ BED \ldots\ldots\ldots\ldots \quad (1)$$

By finding the value of PQ, and the areas of ABEC and BED, we shall obtain the value of PO, and then of OQ.

$$\text{Now } PQ = \sqrt{PF^2 + FQ^2} = \sqrt{\left(\tfrac{AJ}{2} - JL\right)^2 + (HQ - HF)^2}$$
$$= \sqrt{(14{\cdot}66)^2 + \left(22{\cdot}62 - \left\{2{\cdot}93 + \tfrac{1}{3} \times 10{\cdot}56 - \tfrac{1}{2} \times 4{\cdot}4\right\}\right)^2}$$
$$= \sqrt{490{\cdot}8} = 22{\cdot}15$$

Next the area of $ABEC = 10{\cdot}56 \times 88 = 929{\cdot}28$

and the area of $BED = 18{\cdot}1 \times 88 = 1592{\cdot}80$

Substituting the values now found in equation (1), we have—

$$PO \times 929{\cdot}28 = (22{\cdot}15 - PO)\ 1592{\cdot}8$$
$$\text{whence } PO = 13{\cdot}98$$
$$\text{and } OQ = PQ - PO = 22{\cdot}15 - 13{\cdot}98 = 8{\cdot}17$$

The weight of the whole mass of masonry, assuming that one foot in length of the dam is taken into consideration, will be

$$2522{\cdot}08 \times 1 \times 150 \text{ lbs.} = 378312{\cdot}00 \text{ lbs.} = W.$$

and it may be supposed to act at N in the vertical line dropped from the centre of gravity of the whole mass, O. The pressure of the water will be

$$85{\cdot}1 \times 42{\cdot}5 \times 62{\cdot}32 \text{ lbs.} = 225395{\cdot}86 \text{ lbs.}$$

and will act at M, at a distance of one-third of the whole depth from the bottom, and in a direction perpendicular to the face of the wall.

This force may be supposed to act at N, where its direction is intersected by the vertical ON.

To facilitate the working out of the result, resolve the pressure of the water, which may be called P, into two forces; one, W′, vertical; the other P′, horizontal, at N.

Complete the parallelogram NVTU.

Then $NV = TU = NT \sin TNU$.

$$\text{Now } \sin TNU = \sin CAJ = \frac{4{\cdot}4}{88{\cdot}11} = 0{\cdot}05$$

$$\text{Therefore } NV = 0{\cdot}05 \times 225395{\cdot}86 = 11269{\cdot}79 = W'.$$

$$\text{and } NU = P^1 = \sqrt{(225395{\cdot}86)^2 - (11269{\cdot}79)^2} = 225113{\cdot}93.$$

The forces acting at N will thus be $W + W'$ in the direction of the vertical OS, and P^1 in the direction NU.

Complete the parallelogram NSRX, making NS and NX proportional to the forces $W + W'$, and P^1 respectively.

$$W + W' = 378312{\cdot}00 + 11269{\cdot}79 = 389581{\cdot}79.$$
$$\text{and } P^1 = 225113{\cdot}93$$

$$\text{Now } SN : SR :: W + W' : P^1 :: 389581{\cdot}79 : 225113{\cdot}93.$$

$$\therefore SR = \frac{SN \times 225113{\cdot}93}{389511{\cdot}79}$$

$$\text{and } SN = SY - NY = 29{\cdot}33 - (Ya + aN) = 29{\cdot}33 - (1 + aN)$$

$$\text{Again } aN = \tfrac{1}{20} \times aM = \tfrac{1}{20}\left(HF + FY + \tfrac{1}{20} \times 1\right)$$
$$= \tfrac{1}{20}\left(5\ 28 + \frac{44 - 29{\cdot}33}{20} + FY + \tfrac{1}{20}\right)$$

and FY : FQ :: PO : PQ

$$\therefore FY = \frac{FQ \times PO}{PQ} = \frac{16{\cdot}61 \times 13{\cdot}98}{22{\cdot}15} = 10{\cdot}48$$

$$\therefore aN = \tfrac{1}{20}(5{\cdot}28 + 0{\cdot}733 + 10{\cdot}48 + 0{\cdot}05) = \frac{16\ 543}{20} = 0{\cdot}8271$$

$$\therefore SN = 29{\cdot}33 - (1 + 0{\cdot}8271) = 29{\cdot}33 - 1{\cdot}8271 = 27{\cdot}51$$

$$\text{and } SR = \frac{SN \times 225113\ 93}{389581{\cdot}79} = \frac{27{\cdot}51 \times 225113\ 93}{389581{\cdot}79} = 15{\cdot}63$$

$$\text{Now } CS = HY + \tfrac{1}{20} \times SY = HF + FY + \frac{29\ 33}{20}$$
$$= 6{\cdot}013 + 10{\cdot}48 + 1{\cdot}466 = 17\ 959$$

$$\text{and } CZ = \tfrac{1}{2}\, CD = \frac{46\ 75}{2} = 23{\cdot}375$$

$$\therefore SZ = 23\ 375 - 17{\cdot}959 = 5{\cdot}416$$
$$\text{and } ZR = SR - SZ = 15{\cdot}63 - 541 \doteq 10{\cdot}22$$

The resultant R, therefore, passes through the base at a little less than one-fourth the width of the base, which is 11·69 from its centre.

Rankine, who is perhaps our best authority on the subject of the stability of retaining walls, or dams, says, that except when the foundation is rock, one-fourth of the width of the base from the centre is the limit for the resultant, but that in the case of a very firm foundation this limit may be exceeded. It has, however, been thought advisable to give the dam for the Moota Reservoir some extra strength, and the resultant passes even within the limit laid down by Rankine for a dam on an ordinary foundation, though the Moota Dam will be founded on rock. No credit, moreover, has been taken for the aid that will be obtained from the bank of earth which will be heaped against the dam on both sides to check leakage.

The weight of a cubic foot of masonry has been obtained by actual experiment on rubble stone walling at Poona.

Calculation to show that the Waste Weir, as designed, is capable of carrying off a quantity of water equal to the discharge of the River Moota during the greatest known flood.

The greatest flood remembered by the inhabitants of the village of Kopreh, close to the dam site, occurred in 1861, and from information obtained from the people, it has been calculated that the discharge of the river on that occasion was 82,079 cubic feet per second. The waste weir must therefore be of sufficient dimensions to carry off at least that quantity of water.

The length of the waste weir, when the water is passing over its crest at a depth of 5 feet, is 1,658 feet. Of this length 990 feet is more than 10 feet high and consequently has a clear overfall of 5 feet. The remaining portion, 668 feet in length, is less than 10 feet high, and is consequently drowned to a probable average depth of 2 feet 6 inches.

The discharge of the waste weir, when water is going over its crest at a depth of 5 feet, is therefore as follows :—

For the first portion,

Discharge $= 990 \times 5 \times 12\frac{1}{2}$* $= 61{,}875$ cubic feet per second.

For the second portion,

Discharge $= 668 \times 5 \times 10\frac{11}{12}$* $= 36{,}461$ cubic feet per second.

Total discharge $= 98{,}336$ cubic feet per second.

The discharge of the river during the greatest known flood being 82,079 cubic feet per second, the waste weir is capable of carrying off, $98{,}336 - 82{,}079 = 16{,}257$ cubic feet per second in excess of what is likely to be required of it.

* *Vide* Neville's Hydraulic Tables.

No. CLVII.

IRRIGATION OF SINDH.

Memo. by Colonel R. Strachey, R.E., *Inspector General of Irrigation, on the extension of Irrigation in Sindh.*—31*st January*, 1867.

The rain-fall in Sindh is so small, that cultivation may be said to be almost impossible without the aid of irrigation in some form. The ordinary means of obtaining water for this purpose is to draw canals from the Indus. But it has been beyond the power of the people to maintain a supply of water in their canals, excepting during the season of the inundation, which corresponds to the rainy months of other parts of India, and to the agricultural khureef season. It follows that, as a rule, the cultivation of Sindh is limited to a khureef crop; and the rubbee, or cold season crop, is less than one-tenth of the whole. Further, the produce of the khureef crops is in a great measure consumed in the country, supplying the food of the population and their cattle. The more valuable cereal grains and oil seeds are the produce of the rubbee crops, and from the causes that have been mentioned, the quantity of these is very small, and under existing circumstances is not likely to be increased to any sensible extent.

The cultivation dependent on the canals may be divided into two great classes:—*First*, that which can be carried on with water naturally flowing over the surface of the land, in Sindh termed *Moke*, and equivalent to *Tor* of the North-West Provinces; and *second*, that which requires the water to be artificially raised to lands, the surface of which is above the water-level of the canals, in Sindh called *Churkee*, and in the North-West *Dál.*

The moke cultivation is far less certain and less valuable than might at first sight appear likely, consequent on the almost entire absence of control over the level of the water in the canals. This level simply depends on the rise and fall of the river, and excepting in some few specially favorable cases, the risk of the cultivators in moke cultivation is very considerable, and the relative value as compared to churkee, greatly reduced.

The churkee cultivation is so called from being dependent on the use of the "churka," or Persian wheel, by which the water is lifted to the necessary level. It is probable that considerably more than one-half of the whole cultivated area is churkee land, and it is not likely that the average height to which the water has to be raised is less than 5 or 6 feet. It will be obvious that a very great expenditure of labor is requisite to lift water in this manner. Major Lambert, the Collector of Kurrachee, has got together a great number of estimates of the cost of this operation, and he reckons that it amounts, on the average of the whole Province, to about Rs. 15 an acre. It is wonderful how the country can support such a burden on its agriculture. The charge on the Sindhee peasant, over half of the Province, to place him in the position in which nature places the agricultural community of most countries without any cost, by means of the regular rain-fall, is not less than is paid in England as the whole amount of rent.

But besides these difficulties, others of hardly less importance arise from the rude manner in which the irrigation channels have been formed in the first instance. Want of stability in the heads of the main canals; obstruction of the channels by the deposit of silt, due to irregularities of inclination, or other causes; injuries to water-courses and adjacent lands from the breaching of embanked channels, ill-designed or constructed; submergence of lands by reason of the escape of water from canals, the supply in which has been in excess of the requirements for irrigation; injuries of various descriptions, arising from the Indus floods breaking into the water-courses and the irrigated lands: these are some of the more important defects to which the present system of irrigation is liable.

Till the present time, there has been hardly any application of engineering science to the improvement of this state of things, and the existing Canal Engineers are little more than superior Overseers of the annual canal clearances, under the direction of the Revenue District Officers. Some improvements, not without value, have been made from time to time in the

rude system of canals which existed when Sindh first became a British Province, and in the Shikarpoor Collectorate, the supply of water has been sensibly increased with a corresponding distinct increase of cultivation and revenue. But, as a whole, the condition of the country and the people must be regarded as almost stationary; and that this should be the case seems quite sufficiently explained by the adverse combination of circumstances which have been mentioned.

The irregularity of the flow of the canals, and their rude character, often leads to a wasteful use of the water in moke lands. The limitation of the quantity of water supplied by the canals, combined with the absence of rain, prevents the land recovering itself after cropping, and induces a practice of long fallows of two or three years; this leads to very slovenly husbandry, the ground being seldom properly cleared of weeds and jungle. The heavy labor attendant on the raising of the water, restricts greatly the extent of land which might, under more favorable conditions, be tilled by the existing population. The almost complete absence of a rubbee crop, although the climate and the greater part of the soil is believed to be as favorable for its production in Sindh as in the North-West Provinces, deprives the cultivator of what, under a happier arrangement of water-supply, should be to him a source of great comparative wealth and absolute prosperity. The poverty and the stationary material position of the population, and the small amount of exportable produce which comes into the markets prevent the expansion of trade, opposes the growth of Kurrachee, the port of export, and starves the Railway which leads from the agricultural districts to this port.

The obvious remedy for all these evils is to be found in the substitution of perennial, for the existing intermittent, irrigation canals, and of water delivered at the level of the surface, instead of at a level which requires that it should be lifted by animal power. If water could thus be given to the whole Province (excluding, of course, those parts which are sandy desert, and naturally incapable of culture), it would be but little, if at all, inferior in productive capacity to the best Districts of India; and making allowance for all the barren regions, Sindh would yet remain one of the most important Provinces of the British territories.

And there is much reason to hope that such a remedy may be practically possible of application in the chief part of the culturable country. It will, of course, require very careful consideration before the needful works for

carrying out such a change of system in the irrigation of the Province are put in hand; and at the present moment the only essential thing is to arrive at a conclusion whether the objects to be gained by success, and the prospect of such success are of that nature which should induce the Government to take the necessary steps to order further investigation, and to determine that the requisite works should be carried out if these investigations are satisfactory.

It may be assumed that there is no further need for discussing the character of the objects to be gained; their paramount importance is self-evident.

As to the prospects of success in accomplishing the ends in view, there are two principal lights in which the matter must be considered: *first*, the Engineering; and *second*, the Financial. It cannot be properly said in this case that such works as are suggested are strictly necessary to protect the country from famine. There is already sufficient safeguard against this extreme evil. What is sought is to improve the position of the population by greatly increasing the facilities for agriculture. The obligation on the State to do this, unless at all events there be no attendant increase of charge put on the general finances, can, perhaps, be hardly pressed with justice to the interest of the community as a whole; and it may fairly be accepted as a criterion by which to guide our action, that the works shall be distinctly profitable to the State. This point, therefore, will call for careful examination.

On the engineering question much need not be said beyond what will suffice, as *primâ facie* evidence, that the scheme as a whole is practicable. The Indus supplies what is virtually an unlimited quantity of water, and the levels of the country are known to be such as will admit of the easy formation of canals having the needful requisites. Nature has happily provided many spots which appear quite suitable for permanent heads for perennial canals, without involving the construction of very difficult or expensive works. Such are Rohree and the opposite bank of the Indus at Sukkur, Sehwun, Kotree, and Jurruck. At all these places solid rock formations occur on the river's bank, and the channel has, for a very long period, remained constant at these localities. Above Sukkur no rock occurs in the river bed, but there is no reason to doubt that a permanent canal head could be kept open where there is no rock, though at what cost, and with what general financial results, must depend on circumstances now

unknown. On the whole, the facilities for canal construction in Sindh are singularly great.

The question has long been discussed, whether the large quantity of silt carried in suspension by the Indus would not be a cause of such obstruction to any perennial canal as would virtually make it useless. I regard such fears as quite chimerical, but it may be desirable to state briefly my reasons for saying this. First, it is a fact that many of the existing large inundation canals remain open permanently without sensible silt deposit. Next, where silt is deposited, it may unhesitatingly be attributed to the direct operation of causes which should not come into play in properly designed canals. In the existing canals, these deposits most frequently occur either near the mouth or at the extremity. In the first of these cases, the deposit is commonly the result of the erosive action of the river on its bank near the canal mouth. The water under these circumstances becomes abnormally charged with earthy and sandy matter as it enters the canal, and, as a matter of course, much of this is dropped shortly afterwards. When the canal mouths are free from such erosive river action, and the general slope of their beds is sufficient, they remain unobstructed. The obstruction of the lower extremity of the canals is the immediate result of deficient fall, and in many cases almost total stoppage of the current of water. These defects could not exist in properly designed channels. On the whole, the deposit of silt, wherever it occurs, is the result of irregular river action, or of irregular velocity within the canals. The result of the improved system would be to arrest the river action on its banks at the mouth of the canal, and to preserve the velocity of the water within the channels at a suitable uniform rate which should prevent the silt in suspension being deposited until it is carried out into the fields, or the very smallest of the water-courses. The increased height, at which the water-surface would be maintained in the canals, would materially assist in obtaining an improved velocity in the distributing channels; and the same result would be caused by the concentration of the supply into fewer and larger canals which would follow the suppression of some of the far too numerous cuts which have been formed in a state of society where there was no authority to exercise a proper control over the economical distribution of the water. It is the common belief that silt held in suspension is an absolute advantage to the cultivator if it can be distributed with the water over the surface of the land. If any deposit of silt should take place in the minor

channels, in which the velocities are likely to be least, and the levels less under engineering control, it can be removed without sensible practical inconvenience, and with the least amount of labor.

I may here conveniently refer to a point which seems to call for special consideration in the formation of any project for improved irrigation works in Sindh. Where irrigation is introduced into a country for the first time, the arrangement of the minor distributing channels may be controlled by the Engineers almost as completely as that of the chief feeding lines of canal. But in Sindh, where all cultivation at present depends on irrigation, it seems almost obligatory to make use of the existing minor channels, if not exclusively, at least to the very utmost extent that is possible. The necessity for this will be apparent when it is remembered that the whole fabric of property in land is, so to speak, built up upon the net-work of water-courses which supply the great essential for all cultivation. The inhabited and cultivated lands follow the lines of canal. Where the revenue settlement has been completed, it has been based on the supply of water by the existing channels. To do otherwise than continue to supply the water by these channels would not only call for a very great additional amount of labor for the excavation of new water-courses, but would tend most seriously to disturb the tenures of land and everything connected with the agriculture of the country. The aim of the Engineers, therefore, should be to introduce water as early as possible, and with the least possible disturbance of the existing net-work of channels, on the improved system. It would be their business, at a later period, to weed out by degrees all the really objectionable features of the distributing channels first forced upon them. It will, of course, be possible that, in some cases, important modifications in supply channels may be unavoidable from the first, but so far as I am able to judge, these should be exceptions to the general rule as before stated. It is my belief that the adoption of this system will in all respects be the most desirable, whether regard be had to the interests of the cultivator; of the State as superior landlord; of the Exchequer in the matter of first cost and eventual speedy return; of the Engineers in obtaining a proper practical knowledge of the requirements of the country for its irrigation, and a gradual but complete power of control over the supply of the water in the most thrifty manner. It is necessary to bear in mind clearly that from the very conditions of the problem, our Engineers will come to the task imposed on them without a detailed practical knowledge of the exact require-

ments of the country in respect to water, and that their position, in the face of a population which has practised irrigation from time immemorial, is very different from what it might have been in a country into which canals were to be introduced for the first time.

The condition which for these reasons I regard as obligatory, of working the new system of irrigation through the existing distributing channels, it is almost needless to say cannot be productive of anything but saving of expense, time and labor; and under such an arrangement, the full benefit of the improved system will be obtained by the people and the State in a far shorter time than could be reasonably expected in a country new to irrigation, and requiring to be provided with distributing channels. One of the chief causes of the slow progress of irrigation from the Ganges Canal is understood to have been the want of minor distributing channels.

Of course it is impossible to offer an opinion of any value as to the probable cost of works such as have been spoken of, without first obtaining detailed designs and estimates. But without any precise knowledge of the exact cost, some useful light may be thrown on the financial part of the discussion by considering the probable return from an improved system of irrigation, and calculating the amount of capital which it would cover.

The total area of land under crops watered by the canals maintained by the Government in Sindh, is at present about 1,200,000 acres. The average combined charge for land revenue and water is about Rs 2-4 per acre. It will certainly be a very moderate estimate if we reckon that, under a system of high level water-supply, permanently kept up, and completely under control, an additional charge of Rs. 1 per acre might be made on land actually cropped under irrigation, raising the total charge to Rs. 3-4 per acre. In the North Western Provinces I believe that the average charge would be as much as Rs. 4-8, and in Madras it would be never less than Rs. 5, and often more. Next, it may be reckoned that for the khureef crop in Sindh, a constant flow of water of one cubic foot per second will water about 50 acres of land. This is considerably less than the corresponding area in Madras or the North-West, but allowance must be made for the larger quantity of water required in a country without rain. From actual observation in Sindh on one of the canals in the Hydrabad Collectorate, one cubic foot has been found to water 68 acres. On other canals a much smaller result was found.

If we then assume that, out of the existing area, one million acres could

be brought under the improved system at 50 acres per foot, this would require a total water-supply for the whole Province of 20,000 cubic feet per second, which may be considered as equivalent to three canals, each as large as the Ganges Canal.

It will be remembered that the existing cultivation is exclusively khureef. With the perennial supply of water, a rubbee crop may be reckoned upon. Now the consumption of water for rubbee irrigation is much less than for khureef, and making a reasonable allowance as before for the want of rain in Sindh, one cubic foot of rubbee supply may be reckoned to irrigate 100 acres. Therefore the new rubbee crop will amount to two million acres.

The increased revenue will then be 1 Re. per acre on the old acreage, and Rs. 3-4 on the new acreage, that is—

	RS.
1 million acres, at Re. 1, ...	10,00,000
2 " " 3-4, ...	65,00,000
Total, ...	75,00,000

showing a total increase of revenue of 75 lakhs gross, or £750,000 yearly.

At the rates for land and water combined in force in the North Western Provinces, the total gross increase would be approximately—

	RS.
1 million acres, at Rs. 2-4, ...	22,50,000
2 " " 4-8, ...	90,00,000
Total, ...	1,12,50,000

showing a total of 112½ lakhs, or £1,125,000 yearly.

It will next be necessary to estimate the probable charges against this increase. For the canal maintenance and establishments, 12 annas per acre irrigated is not likely to be exceeded, judging by the results of the North Western canals; and even as small a charge as 8 annas an acre is likely to suffice. This charge, at the 12 annas rate, would amount on three million acres to 22½ lakhs yearly. Against this has to be set off the present charge for the same purposes, which may be taken at 3½ lakhs, leaving a net increase of charge of 19 lakhs. To this must be added, however, a sum to cover the additional charges connected with the realization of the increased land revenue. Taking the approximate rate of charge on this account as 10 per cent. on the revenue realized, the addition would be 7½ lakhs, or 11½ lakhs, according to the total rate realized from the land.

Under the first hypothesis of a total maximum charge of Rs. 3-4 per acre, the net increase of revenue would be 48½ lakhs, and at the maximum rate of Rs. 4-8 per acre, it would be 86 lakhs. The former amount would be equivalent to 5 per cent. on about 9½ millions sterling; and the latter to 5 per cent. on 17 millions.

The inference that may be drawn from these calculations is, that if such an increase of cultivation as is spoken of can fairly be anticipated to follow the improved system of irrigation, it would, on the lower estimate, not be unprofitable to the State to spend 9½ millions on the requisite works, and on the higher 17 millions might be spent. Of course it is not for a moment implied that this gives any key to the actual outlay really likely to be necessary, and all that is desired is to show that, on a very moderate estimate of areas and rates of profit, there is *primá facie* evidence that a large outlay of capital would be covered. It may be added that the Ganges Canal, which is acknowledged to be a very expensive work, is likely to cost when complete, rather more than 3 millions sterling. It was before remarked that, to give such an extent of irrigation, as has been reckoned upon, a supply about three times that of the Ganges Canal would be required. On the standard of the Ganges Canal, therefore, the cost of the works might be taken at 9 millions, so that even at this very high rate of cost, the works would probably be remunerative. If an opinion on such a subject is to be hazarded in the present position of the question, it might, perhaps not be unreasonable to consider the Ganges Canal standard fully one-third too high for the much more favorable circumstances of Sindh; and at such a rate, six milions sterling would be the whole sum needed, on which, at the lowest rate of income, a return of £485,000 yearly would be realized, being above 8 per cent. At the higher rate, the return would be £860,000, or 14 per cent.

I would repeat that it is to be understood that the above figures are only intended to show, on such data as can be got, the probably eventual operation of the improved system of irrigation. Time would be required both for the outlay of such large sums, and for the full realization of the entire profits; on the other hand there is every reason to suppose that considerably larger areas of cultivation, and considerably higher rates of charge, could eventually be attained. I conclude therefore that, on the whole, it is fair to anticipate that the interest on any amount of capital really required for such works would be covered by the returns at an early period, and

that the prosecution of the proposed further investigations, and the preparation of suitable projects and estimates, is entirely justified.

I have reckoned on a total cultivated area of 3 million acres, and it will be as well to show how far such an extent of land is likely to be available. I estimate that the entire area of the land that could be watered on the right bank of the Indus, between Sukkur and Sehwun, is 3½ million acres. On the left bank of the Indus, between Rohree and Hyderabad, the total area of British territory is about 2½ million acres. Together, this supplies 6 million acres, and rejecting one-fourth as an allowance to cover barren or unirrigable land, there would remain 4¼ million acres irrigable. In the North West Provinces, it is understood that about one-third of the culturable land is irrigated yearly in the best cultivated districts. But in Sindh, where the whole cultivation requires irrigation, a larger proportion must be taken, and it seems fair to assume that one-half may be irrigated at one time. This would allow of alternate years for fallow for all land, one crop only being taken in each year, which seems amply sufficient. In the area designated we should, on this basis, have 2¼ million acres irrigated yearly, leaving three-fourths of a million to be provided in the lower part of the Delta, and on both sides of the Indus above Sukker, or by a larger amount of land under crop at one time. This additional quantity might very fairly be expected to be obtained from these sources.

As to the power of the existing population to extend the area of cultivation from one to three million acres, it may be said that the relief obtained by the cessation of the lifting the water, will release a very large amount of labor which will be immediately available for extending the area under crop at one time. The money value of this labor may be taken at about Rs. 15 per acre on 500,000 acres, or Rs. 75,00,000. The saving of such an amount in labor, whether it is sufficient to meet the full demand for so large an increase of cultivation, as has been reckoned upon or not, must have a very great influence on the progress of the Province; and even if there be some exaggeration in the cost of this labor, it is almost certain that the real relief will be so great as to give an entirely different character to the agriculture of Sindh.

Although my visit to Sindh has been limited to a short period, and my means of forming sound opinions on matters of detail have, therefore, been restricted, it may be useful if I indicate generally the direction in which it has appeared to me that such investigations should be carried out. In

doing this, however, it is fitting that I should disclaim any intention of doing more than offering suggestions for the consideration of the Officers who may be charged with such a duty, and placing in a somewhat more definite light the character of the operations which I regard as so desirable.

A project was prepared some years ago by Lieut.-Colonel Fife, R.E., for a perennial high level canal to be drawn from the Indus at Rohree. For reasons which need not be referred to, no action has yet been taken on this scheme, though it was strongly supported by the present Governor of Bombay, who at that time was Commissioner in Sindh, much on the grounds which have been adduced in the earlier part of this Memorandum. This project, however, provided for a small supply of water only, 1,400 cubic feet per second, and was intended to be worked altogether apart from, and in addition to, the existing system of inundation canals. This indeed was a natural course to suggest at that time. Now, that opinion has so greatly changed as to the proper system of dealing with works of irrigation, and that more comprehensive views can be put forward with reasonable expectations of their receiving attention, such a project must be regarded as insufficient. I have discussed with Lieut.-Colonel Fife the extension which might properly be given to this project so as to bring it into relation with such a general scheme of irrigation as that which I advocate. The conclusion to which I have come is, that this canal should carry about 7,000 cubic feet of water per second, and should supply the whole of the Hyderabad Collectorate as far as the Foolailee Channel. It should be so arranged as to throw water into all the canals now fed from the Indus between Rohree and the mouth of the Foolailee.

The Foolailee is so large a channel, and carries so large a body of water in the inundation season, and is in such good general condition, that it seems desirable to maintain it at all events for the present. The channels which now flow from its left or northerly bank will all be supplied from the new canal, and the water saved will go to increase the quantity available on the south. If needful, an additional head might be opened opposite to Kotree near Hyderabad, for the supply of the lower portion of the Delta, and a similar work could be constructed opposite Jarruck. It is probable that the canal from Rohree will give a sufficient supply of water for the rubbee cultivation throughout the Hyderabad Collectorate. It is questionable how far rubbee can be profitably raised in the lower part of

the Delta, and it must be left for further investigation to show the precise form which should be given to the works for this portion of the Province. Both at Jurrack and Kotree, facilities exist for the formation of dams such as the Madras Anicuts, and, on the whole, there is nothing to prevent a very ample water-supply being given to the eastern half of the Delta.

On the left bank of the Indus, above Rohree, there is less apparent facility for improving the irrigation. There is no permanent bank and the country is liable to heavy inundation. But there is no reason to question the practicability of maintaining a permanent canal head at some suitable point, or of protecting the country which is now flooded.

On the right bank of the Indus, above Sukkur, the conditions are more favorable than on the left bank, but there may be difficulty or expense in maintaining a permanent head. At Sukkur there is a very favorable locality for a canal head to supply the region between Sukkur and Sehwun, at which place the alluvial plain of Sindh is cut off by the hills which there abut directly on the Indus. It seems probable that a single large canal, of about the same size as that proposed for the left bank, viz., to discharge 7,000 cubic feet per second, would supply the whole area of the Shikarpoor and Kurrachee Districts between Sukkur and Sehwun. The water-supply in this part of the Province is at present much more ample than in Hyderabad; but from the absence of a proper engineering control over the supply, considerable danger is incurred of serious floods, and as a fact, injury from this cause is too frequent. From the strong slope of the surface towards the west, the extremities of the distributing channels in many places require to be embanked, and this having been carried out without a proper system of levels, and without due attention to the precautions required under such circumstances, much waste of water and injurious flooding of land takes place.

On the east, or left bank of the Indus, the land is generally so high as to require the natural fall of the surface to be economized to secure a satisfactory slope for the distributing channels. Here the first object of the Engineers will doubtless be to bring in the main supply at an improved level as early as possible. This being done, the existing channels will be capable of doing greatly increased irrigating duty, and their thorough re-arrangement may be carried out by degrees afterwards.

On the right, or west bank, I am inclined to think that attention is at once required to the main distributing channels; and that by placing these

in a position of proper efficiency as regards their levels, having due regard to their eventual character as channels to carry a high level supply, great immediate improvement could be secured. The fall from the Indus to the south-west is so great, moreover, that real danger of a serious nature is incurred by leaving the main channels open from the river without engineering control. The success which is claimed for some of the canals made by the District Revenue Officers, and particularly that called the Fordwah, is undoubted; but it would be a great misfortune if, from the want of efficient power of control over the water entering such cuts, a calamitous flood were to happen, and there is every appearance of such an event being at least possible. The head sluice of the Forwah is in a very critical condition, and if it were carried away, it would not be easy to save Larkhana from a damaging flood, if the result was not something of a much graver sort, such as a large portion of the Indus breaking out over the country in that direction.

The country between Sehwun and Jurruck is hardly susceptible of perennial irrigation from the Indus, and calls for no further comment.

The western Delta, so far as it may be found to require improved irrigation, can readily be supplied from Kotree or Jurruck. It is from this quarter also that it is probable that Kurrachee must look for a fresh water-supply, of the abundance which seems requisite for a town and port of the importance which it is likely to assume. I see no engineering difficulty in the way of sending down a copious supply of fresh water into the Garra Creek from Jurruck or Kotree, and thence carrying it, by help of a weir, across the Mulleer River to Kurrachee. By avoiding all expenditure that was not essential for such an object, it could, I think, be attained for an outlay not incommensurate with its importance, but of course exact surveys and estimates alone can test speculations of this nature.

It only remains for me to refer briefly to the extreme eastern Districts of Sindh, Thurr and Parker. These now receive a limited supply of water during the inundation by an old channel called the Narra, fed by a new head constructed by our Engineers, drawn from the Indus at Rohree. A new Canal has also been excavated from the end of this old channel, and is known as the Mitrow Canal. From various causes, this canal has not been so successful as could have been desired, or was anticipated. The efficient source of these causes of want of success will, I think, be suffici-

ently found in the absence of a proper professional administration for irrigation operations in Sindh; and the removal of this defect will, I have no doubt, be very soon followed by the application of all needful remedies to the shortcomings of the Mitrow Canal. There are some other minor channels leading from the Narra, lately dug, which have already done much good in extending cultivation; and there should be no great difficulty or expense in considerably adding to the supply of water thrown into these districts, either by the Narra Channel, or from the surplus of the new main Hyderabad Canal, or from the Foolailee, or some new channel taken from the Indus near Hyderabad.

I shall now proceed to make some observations as to the fiscal system which seems likely to be best suited to the condition of things which would exist were the proposed irrigation works carried out. The question at once arises, whether the whole of the State demand should be levied in one sum as at present, or whether a separate water-rate should be levied: and if so, under what sort of system and with what objects? At first sight there is an appearance of simplicity in the present system which recommends it as preferable to the confessedly artificial plan of levying a separate water-rate where, as a fact, cultivation is not possible without irrigation. But further reflection seems to me to show that, in truth, the land revenue is fixed on a perfectly artificial system, and that when a settlement of the revenue has been made, the charge on this account no longer, so to speak, represents agricultural facts, but is a deduction from them. So long as the land revenue is directly based on the actual produce of any field under cultivation, such cultivation being impossible without water, to separate the charge for the water must of course be quite an arbitrary proceeding. But as soon as the land revenue becomes an average or estimated sum, which will satisfy the Government as a composition for a term of years, it is just as easy and simple to separate this into two parts, as to take it in one sum, if there be any sufficient cause for doing it. The question therefore is, whether there is such a cause; and I think it will readily be shown that the system of making the separate charge for water, which has been adopted in other parts of India, should eventually be followed in Sindh also.

If the supply of water were unlimited, there would be no reason for controlling or checking its use. But this not being the case, and the value of the water being so great, it becomes very important that no

waste should be allowed; that the available supply should be distributed equitably, having regard to the area of land under cultivation and prescriptive rights of priority of enjoyment; and that the State which supplies the water at the general expense of the country, should receive in payment for it a fair sum to cover the actual cost of maintenance and the interest on capital, and to provide a reasonable profit in aid of the general resources of the State. Now, the introduction of systematic irrigation is essentially a tentative process. It is only by experience that it can be ascertained how much water is required for the several qualities of land and crop, and what is its value; and the first duty of the irrigation Engineer is to endeavor to ascertain these points. For the former purpose, he measures the irrigated area and finds out what extent can be watered by a given volume of water. In like manner, in fixing and apportioning the charge for the use of water, it is almost essential to begin by a calculation based on the area of land irrigated. In a more advanced stage it becomes possible to make compositions at fixed sums, or to regulate, the charge according to the volume of water actually supplied; but, practically, neither of these courses can be adopted with advantage until sufficient experience has been gained, under a system of crop measurement, of the actual wants of the lands to be watered, and of the value of the water as supplied for irrigation.

On the introduction of improved irrigation in Sindh, it will thus be necessary to ascertain the actual areas irrigated: *first*, to get data for calculating the proper irrigating duty of the water; and *second*, to apportion the increased charge fairly. Even if the increased charge were levied simply as an increased lump-sum of land revenue, it must in detail be arrived at by a consideration of the actual area cultivated with the improved water-supply. And this will hold good whether the Revenue Settlement has been made or not.

Moreover, where the settlement has been made on the basis of the old condition of irrigation, and an improvement in this takes place, it will not be possible with equity to make a *pro ratâ* addition to the whole revenue, because it will not follow that all the land will be benefitted, for every year of the residue of the term, or for any one year. It is only after experience shall have shown what is a fair average estimate for one year, with another of the benefits of the new system, that the water-rate could be brought under settlement with the land revenue.

It seems, therefore, almost an obligatory measure that, in all settled

villages, during the period of transition at least, a separate water-rate shall be taken, on the reckoned actual irrigated area. Now, before the new canals are completed, the whole of Sindh will almost certainly have come under revenue settlement, and therefore the separate water-rate will practically everywhere become necessary.

It further appears desirable that, following the practice of the North-West Provinces, the increased charge for the improved water-supply shall be borne by the cultivator as distinguished from the zemindar. The existing land revenue being in fact that proportion of the rental received by the zemindar from the cultivator, which custom assigns to the State, it appears proper to leave this unchanged until the cultivator's rental is raised. It is probable that in Sindh, as in the North-West, the improvement of the irrigation will not at all of necessity lead to the direct increase of the cultivator's rental. Where, for instance, the customary rental is a certain share of the produce, the profits of the cultivator might be greatly increased by reduction of the cost of irrigation without any important change taking place in the produce which alone regulates the zemindar's interest in the process. Here the cultivator would receive the whole benefit, and should bear the whole charge. Where rents and zemindar's profits practically become increased as a secondary result of these improvements, it will be just that the Government should participate in the increased profits according to the customary rule of the country, and under the terms of any revenue settlement from time to time existing.

In connexion with the matters last discussed, it may be convenient to say a few words on the subject of the Sindh *Huccaba*, or rate to cover the cost of canal clearance. As a fact, no such rate is levied, excepting from Jagheerdars, and the *huccaba* for revenue-paying lands is only distinguished from the land revenue proper by being arbitrarily separated in the Collector's accounts. Before the British occupation of Sindh, the usual custom was, that the Zemindars cleared the canals by their own cultivators, the Government making a small allowance of grain to the work-people, and paying for the supervision, but at the same time taking a corresponding small portion of the produce, under the same of *huccaba*, in addition to the regular land revenue. When Sindh became British, the revenue in kind was commuted into a money payment, and the practice of clearing the canals by unpaid labor was also discontinued, the Government in lieu fixing the money land revenue rate at such an amount as covered the esti-

mated cost of clearance by paid work-people. Of course this was done in a rough and approximate way. Subsequently, when it was pointed out that, under this system, the Jagheerdars got their canals cleared at the expense of Government, it was ruled that they should be required to pay 3 annas per beegah (about half an acre) to make good this charge for all land irrigated by them from canals cleared by Government; and at the same rate, a separation was made in the Collector's accounts of the nominal *huccaba* from the land revenue.

Under a later arrangement, this nominal *huccaba* rate has been ordered to be transferred from the Imperial to the Local Fund income, the charge for the canal clearances at the same time being made a local charge. Obviously, the sole financial effect of this measure is to make a permanent contract with the Sindh Local Funds for canal clearances at the rate of 3 annas per Sindh beegah irrigated. It will suffice if I here briefly state my opinion that such a system is even now needless and objectionable, and that it would be quite inapplicable to the condition of things that would exist, were a proper irrigation administration established in the Province. That the apparent necessity for such a measure should have been conceived to exist, seems to me the result of misconceptions and defects of administrative system, which I may take another opportunity to explain.

It remains for me to refer to one other consideration which should receive serious attention when adopting a policy of providing Sindh with permanent irrigation at a high level. I refer to the grave responsibility which will rest on the State to maintain the works in proper efficiency. Any want of attention to the water-supply of a country so completely without rain, and so thoroughly dependent as it would become on a highly artificial system of irrigation, will be calamitous. A country thus placed is in a position as critical as one in which the entire surface is preserved from the irruption of the sea by dykes.

The conclusion to be adopted in the face of this responsibility should certainly not be that on this account such works should not be undertaken, but that every possible precaution should be adopted to guard against accidents. And having regard to the character of the risk, and to the present comparatively small amount of the population of Sindh, it seems unsafe to trust to the ordinary supply of labor that could be obtained in the open market, to meet all possible emergencies that might arise after such a canal system as I have contemplated had come into operation. Whether for effect-

ing clearances of the channels, or repairing breaches in the embankments, or carrying out any other really essential work, the administration should have the power, under suitable check, of commanding the labor of the entire community to effect what was necessary in behalf of the general interests. If a conscription or an enrolment of the whole number of able-bodied citizens is legitimate for the defence of a country against an armed enemy of the State, how much more legitimate is the exercise of a similar power for the protection of the whole community from the most frightful calamity that can befall it—a general drought and famine. If the tremendous character of such visitations had been estimated at their proper value, some of the blackest pages in the history of the British administration in India would have had no place there; and it would be inexcusable indeed, if, in the face of the lesson which has been lately read to us in Cuttack, any proper precaution was omitted when attempting to deal with the irrigation of a whole Province. A law having such an intention as is here contemplated, exists, I think, in Madras; and something of this nature should be introduced in Sindh simultaneously with the resolution to prosecute the new system of works.

R. S.

No. CLVIII.

BERAR SPECIFICATIONS.

Extracts from Specifications for Ordinary Work and Repairs, as drawn out for the Province of Berar. BY CAPT. H. H. FOORD, A.I.C.E., *Exec. Engineer.*

ROAD METAL WORK.

THE roads in Berar are of four descriptions, viz., sand, moorum, sand and moorum, and broken stone.

Moorum Roads.—Moorum roads will generally be metalled with moorum to a width of 18 feet and a thickness of 1 foot. A coating of 4 inches of the moorum is first to be spread on the road bed, and vehicles allowed to pass over it till it becomes tolerably firm, and is *nearly* but *not* entirely consolidated; men are to be stationed to continually rake in the ruts, as fast as they appear. The second coating of 4 inches is then to be added, and treated like the first; when this is nearly consolidated the remaining 4 inches is to be spread and well rolled with a heavy roller until it is well consolidated. The second and third coats of moorum are to be added during the wet weather. The Contractor will be required to give the road over, with the full thickness of 1 foot of consolidated moorum.

Sand Roads.—The sand is to be clean and sharp, and the thickness will be 9 inches unless otherwise specified. A coating of 3 inches is first to be spread on the prepared earth road, and well rolled until the sand and black soil are prefectly amalgamated; the second coat is then to be given, and the rolling continued with heavy cast-iron rollers, until it is consolidated; the remaining 3 inches are then to be spread and well rolled; the rolling is to

be continued until the surface of the road becomes perfectly smooth, hard, and compact. The sand should be spread during the monsoon, and every opportunity must be availed of, during a cessation of the rain, for rolling the road.

In certain cases, where sand is not procurable of the above description, gravel from the bed of rivers may be used. In this case, the Contractor will be required to sift the pebbles, two sieves being provided for this purpose, one with wires $1\frac{1}{2}$ inches apart, so that all pebbles above that size may be rejected; the other should have spaces of $\frac{3}{4}$ of an inch, and the material which passes through it should be thrown away; it is strictly forbidden to place large pebbles at the bottom of the road and cover it over with gravel of the proper description. The gravel is to be spread in the same way and subjected to the same treatment as specified above for sand roads.

Sand and Moorum Roads.—Roads made of sand and moorum combined are to be made in strict accordance with the directions given above; the thickness of moorum will be 9 inches, laid in three courses of 3 inches each, and one coat of sand 3 inches thick. The whole to be well rolled until consolidated.

Broken Stone Roads.—The stone used shall be black basalt broken into pieces as nearly cubical as possible (all slices and splinters to be rejected), the largest of which, in its longest dimensions not to exceed 2 inches, and none smaller than 1 inch to be used. The Contractor will have to give over the specified thickness of metal after consolidation; unless otherwise specified, the roads will have 9 inches thickness of broken stone metal. The road bed having been thoroughly drained, is to be properly shaped and sloped each way from the centre, so as to discharge what water may penetrate to it; care must be taken not to give this crowning by an extra thickness of metal on the centre of the road, but by properly forming the road bed; upon this bed, a coating of 3 inches of clean broken stones, free from any earthy mixture, is to be spread on a dry day. The traffic is then to be admitted on it, men being stationed to rake in the ruts as soon as formed, and a heavy roller used, till it becomes almost consolidated, but not completely so; (the determination of this time being an important practical point, will be decided by the Executive Engineer); a second coat of 3 inches is then to be added during the rains, and subjected to the same treatment as the first coat; the final coating is then to be spread and the rolling continued until the whole is well consolidated.

Broken Stone Roads on Stone Pavement.—The road bed is to be thoroughly drained and to be properly shaped and sloped each way from the centre; on this a bottom course or layer of stones is to be set by hand in the form of a close, firm, pavement. The stones set in the middle of the roads are to be 7 inches in depth ; at 7 feet from the centre, 5 inches; at 10 feet from the centre 4 inches; and 12 feet from the centre, 3 inches. They are to be set on their *broadest edges and lengthwise across the road,* and the breadth of the upper edge is not to exceed 4 inches in any case. All the irregularities of the upper part of the said pavement are to be broken off by the hammer, and all the interstices to be filled in with stone chips, firmly wedged or packed by hand with a light hammer; so that when the whole pavement is finished, there shall be sufficient fall from centre to sides. After the pavement is laid as directed, the roads shall be metalled with broken stone as specified above. Care must be taken not to disturb the pavement whilst the road is being made; the carts bringing the broken stone must not be allowed to pass over the foundation. The stone for the pavement may be either gray basalt or porphyry; it is not essential that it should be stone of as hard a description as that used for metalling.

Repairs to moorum, sand, and sand and moorum roads, will consist, at the close of the monsoon, in clearing out the side trenches, repairing the slopes of the cuttings and embankments, filling in wheel tracks with material, and well rolling the roads; they will be paid for at a certain rate per mile. When it is necessary to add a fresh coat of sand or moorum, the same will be paid for according to the accepted rates for new work.

Repairs to Broken Stone Roads.—All ruts, deep holes and irregular projections must be filled in and levelled; the road must be put into proper shape and restored to its proper cross-section, by cutting down the sides and filling up the middle part; only a single thin coat of stone shall be applied at a time—not more than a cubic yard to a rod superficial. The surface of the old road may be lightly picked up or "lifted" (with strong short picks) merely burying the point of the pick one or two inches deep, so that the new materials may be more readily united to the old ones. This must be especially attended to on declivities, to prevent the stones rolling down the slope. When the road to be repaired is one which has been originally formed of large stones, no new material shall be brought on it, but the old stones shall be loosened with picks, gathered to the side of the roads, and there broken to the proper size. The surface of the road

having been put in proper shape, the broken stones are to be returned to it, and scattered uniformly and thinly over the surface. Only a small space of road must be broken up at once, say 8 feet in length, and the whole width of the road. The repairs shall be made during the rains. The Contractor will be paid for the repairs, such as filling-in, levelling, breaking up stones already on the road, as day work; the broken stone will be paid for according to the distance carted at the agreed rate per 100 cubic feet, and is to include spreading, ramming and rolling until consolidated.

Bricklayers' Work.

Flooring.—Jelly in chunam floor to be of broken brick and mortar; three parts of broken brick (pieces of brick to be about 1 inch cube) and one part mortar, well mixed together and spread to a thickness of 6 inches, carefully levelled down and beaten until quite smooth, and plastered with plaster composed of one part lime and one and a half sand; the floor to be continually sprinkled with lime water until completed.

Mud flooring is to be made with *pangree muttee* (white earth) and a small quantity of sand, well mixed together with as little water as possible, to be spread and carefully levelled and well beaten down and neatly plastered with a mixture of cow-dung and clay.

Tiled Roofing.—This is of two descriptions, one with flat and pan tiles, on teakwood reepers; and the other with pan tiles, on bamboo matting, and bamboo reepers. The tiles are to be sound, hard and well burnt; each tile is to be dipped in boiling oil twice before being used; flat tiles to be 6 inches square and are to be approved of before being laid. Reepers to be $\frac{3}{8}$ of an inch thick and 2 inches wide; to be laid in long lengths, 6 inches apart from centre to centre.

Terraced Roofing.—Brick-on-edge laid diagonally; two courses of flat tiles; 3 inches brick jelly in chunam; one course flat tiles; and 3 coats of plaster. Terrace bricks to be 5 by 3 by 1 inches.

Bengal Terraced Roofing.—Two courses flat tiles; $1\frac{1}{2}$ inches jelly in chunam, the brick broken very small; one course flat tiles and 3 coats plaster; the tiles are to be dipped in water before being used, and the plastering done with great care and well rubbed down.

Slight Repairs to Terrace Roofs.—Roofs to be scraped and cleaned all over; cracks and slight damages to be filled up and repaired with fine lime,

and brick-dust ground to an impalpable powder, mixed with a little molasses, and tempered to the consistency of stiff putty, and to be finished off in a proper manner.

Repairing Cracks in Terrace roofs with Luckium.—Luckium, prepared as noted below, is to be inserted in the cracks either with a trowel or a thin knife, according to the size of the crack. *Luckium* to be composed of fine cotton, two ounces; slaked lime, twenty pounds; linseed oil, ten pounds.

Carpenters' Work.

The timber used upon all work, except temporary constructions, shall be Moulmein or West Coast teak, of the best quality of the class to which they belong; the balks used for girders shall be of Moulmein teak, of sound heart-wood, hard, compact, and free from shakes, flaws, or sun cracks.

The timber for all temporary structures shall be of khair, babool or such other jungle wood as the Executive Engineer shall approve of; and to be of the best quality, sound, free from sap wood, and seasoned in every respect as well as the teak.

Boarding.—Teak wood boarded floors to be made of well seasoned planks, gauged to the thickness specified, closely fitted, and secured to the floor joints with English screws, countersunk quarter of an inch into the planks.

Teak wood weather boarding battens to be 8 inches wide, laid with an overlap of 2 inches; the rafters being properly notched to receive the battens, which will be of one-half the thickness on the lower edge, that they are on the upper edge; the battens to be fairly wrought, and to be screwed on to the rafter.

Piling.—For Bridges with timber piles and superstructure. The main piles shall consist of sound, well seasoned teak, straight, and 12 inches square; they shall be dammered with 2 coats of best dammer before they are driven, and each main pile shall be firmly shod with a wrought-iron shoe weighing not less than 12 ℔s. The piles shall be driven with a mon key weighing 10 cwts., until by a blow equal to that weight, falling from a height of 18 feet, they do not penetrate the ground more than one inch. In driving the piles, a wrought-iron ring, weighing not less than 8 ℔s. shall be fixed upon the head of each pile; and one ring shall be used for every six piles. The outside piles, under the fender pieces, shall be shod with shoes weighing not less than 8 ℔s. each; and in driving them, the heads are to be protected by suitable wrought-iron rings.

Smiths' Work.

All castings shall be *coated while hot, with hot linseed oil*, or shall be dipped in vessels of hot oil, and shall remain therein sufficient time for the oil, when cold, to form a hard varnish on the surface.

All the bolt holes of cast-iron work shall be drilled. All joints of cast-iron work shall be planed or otherwise brought to a true surface.

Wrought-Iron.—The wrought-iron in all trussed girders and roof trusses to be of the best description of scrap-iron, free from scales and other defects; the plates, bars and angle-iron are to be cut to the precise length, and accurately punched; the holes to be of the proper size for bolts or rivets, and the riveting to be done hot; no joints to the plates or angle-iron will be allowed but those shown on the drawings.

All nuts and screws are to be clean cut, and made to fit well. All bolts to be made from one piece, and all above ⅛-inch diameter to be turned. All bolt holes to be drilled.

Lead Work.—The only plumbers work likely to be required in Berar is lead piping, the lead to be of the best quality and workmanship; all lead pipes to be drawn and are to weigh as follows (the price includes all solder joints, lead tacks, &c., and fixing complete).

Pipe		Weight	
½ inch pipe	to weigh	6 lbs.	per yard lineal.
¾ " "		9½ lbs.	
1 " "		14 lbs.	
1¼ " "		17 lbs.	
1½ " "		21 lbs.	
2 " "		28 lbs.	

Copper and Brass Work.—In any case where it may be required to use thin sheet copper as water-tight sheathing, it is to be tinned on one side.

Tin Work.—Soldering to be 2 parts tin and 1 part lead, for tin; and ⅓ tin and ⅔ lead, for lead.

Painters' and Glaziers' Work.

The paints used are to be the best English paints, to be pure and free from adulteration. Oil used to be pure boiled linseed, and the color is to be well ground, and to a have due proportion of driers. All wood work generally is to be twice knotted, primed, and painted in addition, four times in oil color; and finished with such tints as shall be directed.

In repainting wood work, the old work must first be thoroughly cleaned and rubbed with pumice stone until the old surface is perfectly smooth. All cracks, &c., to be filled in with putty.

Cleaning and Oiling Paint.—The old paint is to be washed with country soap and water, till clean and free from all smoke, stains or dirt, and to be rubbed with linseed oil.

Coal tarring to consist of one coat of well boiled coal tar, laid on hot; the surface on which it is to be laid being first well cleaned from mud or dirt.

Dammering on floor to be prepared in proportions of one part of rosin to seven parts of best coal pitch well mixed together; when boiled, to be laid on the floor half an inch thick; the thickness to be regulated by a straight edge used as a gauge, the surface to be smoothed with a hot iron and sprinkled with a small portion of sand.

Asphalte on Floors.—Prepared asphalte to be properly melted with 5 lbs. of mineral tar, to the cwt.; then laid on the floor in one coat of the specified thickness, which is to be regulated by a wooden straight edge used as a gauge; the surface to be smoothed with a hot iron.

Repairs to Asphalte Floors.—The loose asphalte to be removed, and to be replaced with fresh asphalte, boiled with mineral tar and laid on as in new work to the thickness of the old floor; the edges of the old work to be heated with a hot iron, to unite the old work with the new.

No. CLIX.

DETAIL OF WORKING ON THE GREAT TRIGONOMETRICAL SURVEY.

[A HISTORY of the G. T. Survey of India having already been given in previous numbers of these Papers, it is thought likely to be interesting to many readers if some account is given of the actual *modus operandi;* which has been abridged from the *Practical Instructions* issued for the guidance of the Department by the late Surveyor General, Major-General Sir A. Waugh, R.E. It is of course assumed that the general principles of an ordinary Trigonometrical Survey are understood by the reader.]

The operations of the G. T. Survey of India are carried on in the form of a series of Principal Triangles, originating from, and terminated by, a well determined line,* and upon the sides of these Principal Triangles depend other minor ones, which furnish points at two or three miles asunder, thereby fixing limits to inaccuracy in topographical details.

The direction in which a series of triangles should proceed depends on the subject for which it is undertaken; but, as a general rule, it is desirable to avoid an oblique direction, and to conform strictly to a meridional or longitudinal line; of these the meridional direction is the most favorable condition for geodetical surveys, because any error in the assumed figure and dimensions of the Earth has then least influence on the computed results.

Geodetical operations may be classed under two heads, viz. :—1st, Duties

* The Great Arc and the several Longitudinal Series, which are considered the main operations of the Survey, depend on measured bases. All the other Series depend on sides of the Great Arc or Longitudinal Series (excepting the Calcutta Meridional and the Great Indus Series, which, likewise, connect measured bases. The two last mentioned Series have been executed subsequently to the writing of this paper).

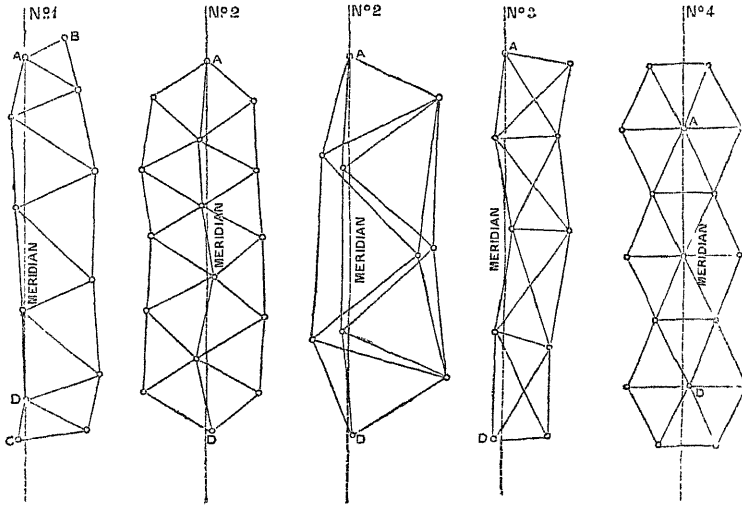
in the Field; 2nd, Duties in the Office. Under the first head are comprised the selection of the triangulation in a skilful manner, and the method of taking the final observations, with due regard to accuracy and precision. Under the second head are included the reduction of the observations, and computations of the final results.

1*st*—*Duties in the Field.*—Although the measurement of a base line is an indispensable preliminary operation in a geodetical survey, and ought, therefore, as respects order of time, to be described first, still, as the Indian bases have already been measured, and the trigonometrical operations now carrying on in the British dominions in India, are all based upon the sides of other Series, it would be needless to lay down any rules for base line measurements. Should any necessity arise for undertaking the measurement of another line, the duty will be executed under the personal superintendence of the Surveyor-General.

The next important operation in conducting a series is to determine the direction of the meridian. There are several ways in which this may be accomplished, but the method most appropriate for geodetical purposes is to measure the azimuthal angle between a fixed terrestrial mark and a circumpolar star at the time of its greatest elongation. It will be most convenient to describe this operation under the head of Final Observations. A knowledge of the approximate position of the meridian is, however, indispensable in selecting the triangulation; but the data for this purpose are generally furnished by the prior Trigonometrical Series, upon which those now in progress are based; or, at any rate, the azimuth can always be determined with sufficient accuracy for the proper selection of stations, by means of a few observations on the Sun a little after sunrise, or before sunset. This approximate method is described in all elementary books.

Selection of Stations.—The direction in which the triangulation is to proceed being known, the next step is to select the stations in a judicious manner, so as to produce the greatest accuracy in the results.

A series of Principal Triangles may be either single or double, as represented below, wherein No. 1 is a single series. A double triangulation may be arranged in several ways; for example, No. 2 is a continued double series; No. 3 is a series of successive quadrilaterals; No. 4 is a series of successive polygons. In practice it frequently happens that all these varieties of figure are combined together in various ways, according to the nature of the country, and the local facilities it affords; but as each method has its

peculiar advantages and disadvantages, it is proper that their relative merits should be duly considered, in order that the most judicious selection may be made which circumstances admit of.

A Azimuth Station. D Azimuth of Verification. AB. Base. DC. Base of Verification

The single series possesses advantages of economy of time and labor and money, as well in the field operations as in the office computations; and it is, consequently, the most proper kind of series to be adopted when circumstances impose a strict attention to these restrictions. For instance, in a level country, like the plains of Hindustan, in which, from the absence of natural elevations, trigonometrical operations are both costly and tedious, every consideration of economy combines to recommend a single series as the most eligible arrangement. On the other hand, the advantage of accuracy will always be found greatly in favor of a double series, which moreover, supplies a check of the most efficient kind at every stage of the work. The continued double series (like No. 2) is chiefly objectionable, because no part of the computations can be finally completed until the field operations are brought to a conclusion; under which state of circumstances the accumulation of arrears of office duty becomes a source of the greatest embarrassment.

This evil may be avoided by that arrangement of a double series, in which it is composed of a succession of quadrilaterals or polygons, because the

computation of each figure can then be brought up independently from time to time, as the observations in the field are successively completed.

Of all geodetical figures the quadrilateral is theoretically the most conducive to accuracy, as well as most economical, because it requires no additional stations, and the equations from which the errors are deduced are proportionably the most numerous. For example, the relative conditions of the quadrilateral and of the usual polygons are as follows :—

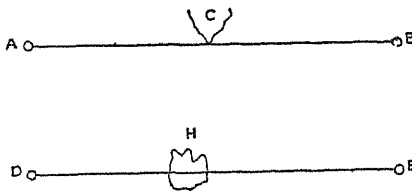
	No. of Stations.		No. of Angles.		No of Eqtns. formed.
Quadrilateral,	4	...	12	...	9
Hexagon,	6	...	18	...	8
Pentagon,	5	...	15	...	7

These circumstances are greatly in favor of a quadrilateral, both as regards economy and precision; but on the other hand, there are practical considerations of importance, which may frequently render the polygon arrangement preferable.

First, it may be remarked that it is extremely difficult to select four stations forming symmetrical triangles, and at the same time so situated, with respect to each other, that from each station the other three shall be distinctly visible. Secondly, the long diagonal rays are unfavorable equally to good observation and to rapidity of progress. The diagonal of a square bears a proportion to the side of the same figure, in the ratio of $\sqrt{8}$ to 2, and it is obvious that in practice one diagonal of a quadrilateral will generally exceed that proportion. This combination of long and short sides is therefore liable to cause detention, on account of the difficulty of observing a distant station under circumstances which form no impediment to the observation of near ones. This embarrassment, however, is not of so serious a nature in a hilly tract as in a level country, where the difficulty of observing long rays is very greatly increased by the density of the atmosphere near the ground; and as, in such circumstances, towers are required to render these stations mutually visible, these structures will become a source of greatly enhanced expense. The curvature of a globular body increases in the ratio of the square of the distance, and it is therefore obvious that the height of a tower adapted to a quadrilateral is to the height adapted to a single triangle, in the ratio of $(\sqrt{8})^2$ to 2^2, or 8 to 4. Hence, a quadrilateral arrangement is totally inapplicable in a flat country; but in a mountainous or hilly region, quadrilaterals should always be chosen when the configuration of the country and other circumstances offer no practical objections of an insuperable nature.

A Meridional Series, as its name implies, follows the direction of the meridian of some fundamental station (A, for example, *vide Fig.* 1), at which station the direction of the meridian must be duly determined by appropriate observations on circumpolar stars. When the Series is composed of single triangles, or of quadrilaterals, it is advantageous to select all the stations on one flank, in such a manner as to coincide as nearly as practicable with the meridian. Those stations which are situated nearest to that line are the most favorable for observing azimuths of verification, which should be taken near the termination of the series, and also at intermediate points, fifty to eighty miles apart, according to the magnitudes of the triangles; because, the larger the triangles are, the less chance there is of accumulation of error, and as the azimuths of verification are intended to detect accumulated angular errors, it is clear that the distance between the azimuth stations ought to depend on the number of intermediate triangles. When the Series is composed of polygons, the central stations of those figures should be selected on the meridian, or as near to it as possible.—(*Vide Fig.* No. 4.)

In a Longitudinal Series, on the other hand, it is desirable that one flank of the Series (or the centres of the polygons) should coincide, as nearly as circumstances will permit, with the parallel to which the Series is intended to conform, and azimuths should be taken at every alternate station, in order that the latitudes and longitudes may depend on observed azimuths alone, and not upon deduced ones, whereby the formulæ for computation will be confined within the proper limits.

In order that the observed azimuths may be as free as possible from those errors which are caused by local attractions, it is desirable that no great mass of high mountains should stand either east or west of the station of observation, nor be so situated, with respect to it, that the portion of resolved attraction in the direction of the parallel should amount to a sensible quantity.

In choosing stations it is proper to avoid intermediate obstacles situated on, or close to, the ray; because if the ray between A and B grazes the side of the mountain C, the ray will certainly be deflected by the vapours which arise from the sloping ground,

whereby the observations at A and B will be more or less injuriously affected by lateral refraction; and if the ray grazes close over the top of the mountain H, then the angles horizontal and vertical will be greatly disturbed. If circumstances, however, concur in admitting of no other choice, it will be desirable always to provide a check by introducing a polygon or quadrilateral at that part of the work, and a secondary station should also be established on C or H, which may be treated as an auxiliary point, for taking vertical angles, whereby the comparative height of A and B may be determined independently of direct observation.

A Principal Series should consist of triangles as large as the features of the country admit of, by which arrangement the number of stations will be reduced to a minimum; moreover, as the errors which are unavoidably committed at each station have a tendency to accumulate in proportion as those stations are multiplied, it follows that the probability of accumulation will be least when triangles are large.

Considerations of economy likewise impose the same restriction, inasmuch as the additional points required for topographical purposes can be obtained at less cost by means of secondary triangles, in which accumulation of error is an evil that need not be dreaded, the limits of inaccuracy being sufficiently established by the principal triangulation. No general rule can be applied with respect to the magnitude of triangles, which must necessarily vary with the configuration of the surface of the country. In a mountainous region with gigantic features (composed of lofty peaks and deep valleys) it would be as difficult as it would be injudicious to select small triangles; and in a flat country it would be absurd to struggle against natural difficulties in the vain endeavour to establish a series of great magnitude. In hilly countries, twenty to thirty miles is a convenient distance for principal stations, and such distances can usually be observed with facility, in all ordinary conditions of atmosphere, by means of helitropes and Argand lamps. When hills are table-topped, as is generally the case where the stratification of the rocks is horizontal, it may be necessary to shorten the sides to less than twenty miles; while, on other occasions, an open country with detached peaks may frequently afford distances of thirty to forty miles with the fairest prospect of good observations. In a level country, such as Bengal, ten miles is the most favorable length of side, and the limits should there be considered eight to fifteen miles.

The triangles selected should be symmetrical, that is, as nearly equi-

lateral as possible, such being the best condition for ensuring accuracy when all the angles are measured, but as it is impracticable to obtain in the field, triangles exactly equilateral, the rule in practice is to admit of no angle under 30°, or above 90°. This rule applies to all the triangles which compose a series, whether principal or secondary; but, in the case of secondary triangles which do not form part of a long series, wider limits are admissible. These limits must also of necessity be extended in the case of a quadrilateral, because the four triangles of which it is composed obviously cannot be all equilateral. The best condition for that figure is when it approximates to the square, in which form no angle will be much above 90°, and none much less than 45°.

In a hilly region, it is a convenient arrangement to detach a well qualified sub-assistant in advance, to choose the stations, and construct platforms; but in a level country it is advisable that the officer in charge of the work should select the stations in the early part of the season, leaving assistants to erect towers, and clear the rays in rear. Towards the end of the season, he should return to the commencement, and begin final observations, while the assistants continue the clearing of rays, and erection of towers previously selected in advance.

These arrangements however depend entirely on the organization of the party and the peculiar capabilities of the members who compose it; but, whatever plan is adopted, with regard to the Approximate Series, the following rules should always be adhered to:—

The stations selected should be on the highest peaks, but as these are sometimes inaccessible, it may be necessary to adopt a lower point. Every effort should, of course, be made to reach the summit when practicable. In the case of a lower point being used, care must be taken that the view is clear in the direction of the stations in advance.

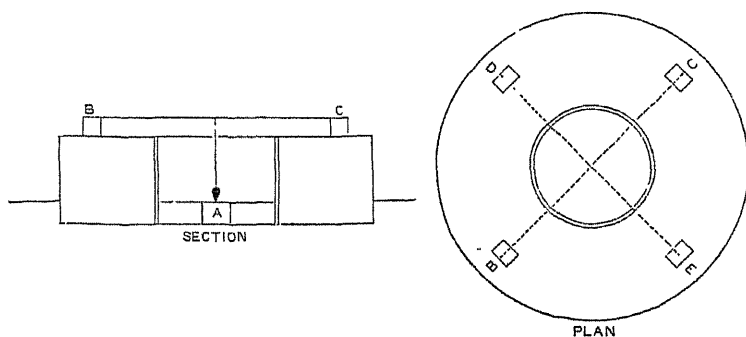
The first business on arriving at a principal station, where points in advance are to be chosen, is to put up the instrument as soon as the atmosphere is clear enough to allow a distinct view. Having adjusted it, you will find out the direction in which you would wish the stations in advance to be, and by means of the level you will judge what points near these directions are likely to be visible from each other, and from the stations with which they are to be connected.

To avoid the necessity of revisiting the station from which the selection is made, it will in dubious cases be found advantageous to select more than

one point from each station in advance, and when you are quite decided as to your choice, the platforms may be constructed.

It is the practice to mark all spots where angles are taken, whether they be principal or secondary stations. The mark is a dot with a concentric circle, cut on stone by means of a pointed chisel. If the mark can be engraved on the rock *in situ* so much the better; otherwise, a large stone, properly marked, ought to be buried in the ground. Over this a small platform is raised, on the summit of which another mark-stone is inserted, and fixed truly vertical over the lower one. The distance between the two marks should be recorded, but all measurements and observations are usually referred to the upper mark, and are so recorded in the angle book records.

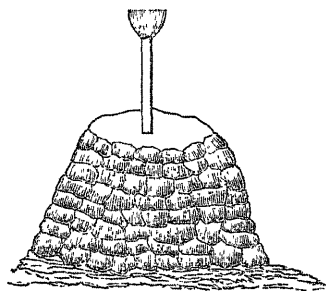
Sometimes, on account of intervening obstacles, it is necessary to raise the platform to a considerable height, in which case several mark-stones are always inserted, and their relative heights recorded.

The method of adjusting mark-stones is as follows :—Let A be the mark at the foundation, either engraved on the rock, or on a heavy embedded stone. Let the external part of the platform be built up to the intended height of the next mark, and place upon it four heavy stones, arranged in a

quadrilateral figure, in such wise that threads BC and DE, stretched diagonally across, may intersect near the centre. Adjust these threads to correspond with a plumb line suspended over the mark A, and when the coincidence is complete, mark the four exterior stones, by pencil lines, or lines scratched with a knife. Arrangements must now be made for protecting these stones, either by covering them over, or appointing a man to watch each, while the pillar in the centre is being built up nearly to the

level of BC, at which height the next mark stone should be fixed and adjusted, to correspond with the cross threads before adverted to.

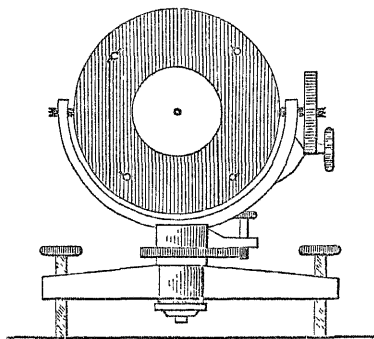
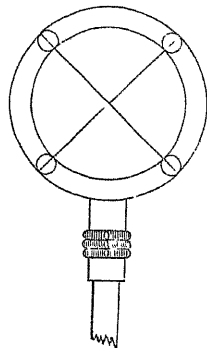
For Principal Stations it is necessary to make that part of the platform on which the instrument rests, separate and distinct from that on which the observer and his assistants walk. The instrument is then said to be duly isolated. Unless this precaution is taken, good angles cannot be expected, as the instrument will be liable to irregular disturbance, according to the position of the observer. The annular space between the observer's stage and the central pier should be filled up with gravel or sand, otherwise screws and other parts of the apparatus may be lost, by falling into it. Besides the upper mark-stone, it is usual to imbed in the pier three picked, flat, heavy stones, for the tripod of the instrument to stand upon. These are called "feet stones," and they should be duly levelled, which will save trouble afterwards in adjusting the instrument.

It is not usual, if it can be avoided, to make isolated platforms at secondary stations. In localities where the ground is very unsteady, such as deep, black, cotton soil, I have found it practicable to steady a theodolite by using pickets four or five feet long, and driving them into the ground, for the stand of the theodolite to rest upon. The pickets isolate themselves for at least one foot in driving. This precaution can only be taken at a new station, otherwise the mark would be disturbed by the process of driving the pickets.

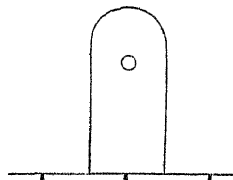
As soon as all the observations have been taken at any station, and it has been observed from all the corresponding stations, it is no longer required for the purposes of the Trigonometrical Survey, and it should have a pile of stones, with a pole and brush, erected over it, in order that it may be visible, and useful, to the detail surveyors. This precaution has the further advantage of protecting the mark-stones from violent disarrangement.

The pole and brush is erected thus: a long straight pole is selected, upon the top of which a brush of twigs is fastened. The pole is placed truly perpendicular over the Station mark, and a pile of stones raised round it, by means of which it is securely fixed. The diagram in the margin will give

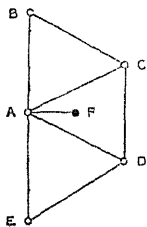
a clear idea of the signal, which is a very economical and useful opaque object for day observations. The pile of stones may be five or six feet high, and the pole about as much longer.

The signals used for the Stations of the G. T. Survey consist of Heliotropes for day observations, and Argand reverbatory lamps, or Drummond lights for night.

The Heliotrope consists of a circular piece of flat plate glass mirror, about 9 inches in diameter, with a small unsilvered aperture in the centre about 0·1 of an inch in diameter, as represented in the figure. This mirror is mounted on a frame which stands on a tripod for the sake of steadiness.

The frame admits of the looking-glass being turned on a horizontal axis as well as on a vertical axis. These two motions in altitude and azimuth are regulated by means of rack work, and they permit the reflection of the sun's rays to be turned in any required direction. In order that it may be directed truly to the observer, a ring with cross-wires, is placed at a distance of about 3 feet; the signalman then looks through the unsilvered aperture in the centre of the Heliotrope and moves the cross-wires until they intersect the distant station. Thus the centre of the Heliotrope, the centre of the wires, and the observer's station form one right line. Now, if by means of the rack work, the mirror is moved in altitude and in azimuth until the sun's rays fall on the wires, it is evident that the light will proceed straight to the observer's Station; but the pencil of rays must be duly bisected by the wires, which intersection can be managed with ease and delicacy, by means of a little circle of white paper placed at the crossing of the wires, upon which paper the reflection of the little aperture in the centre of the mirror may be seen like a small dark speck. When the weather is hazy the signalman will of course be unable to see the observer's station; in which

case, unless a nearer mark has been given to guide him or a directing line has been drawn for him, he will be so far helpless. Under such circumstances, the observer ought to direct one or more Heliotropes towards the man, and keep them playing until he has adjusted his apparatus. Similarly, if the man is careless, and neglects to keep the sun's rays constantly shining in the true direction, the observer has only to flash a Heliotrope at him, to keep him alert.

A Heliotrope of 9 inches, will answer for 90 or 100 miles; for nearer distances it is much too bright to be observed through a Telescope, and the light must be diminished in the following proportion. For distances of 2 or 3 miles (the usual distance of a referring mark) an aperture of 0·25 of an inch will answer, and for longer distances about 0·1 of an inch of aperture per mile of distance will suffice, viz., one inch for ten miles, two inches for 20 miles, and so on, provided always the apparatus is carefully adjusted and the man, who works it, is alert and skilful.

These apertures are cut in a board which stands upon three feet (as shown in the figure) by means of which the centre of the aperture can be adjusted plumb over the Station mark. This board is called a Sight Vane; stones are placed on the tail piece to prevent its being disturbed by the action of the wind. If this sight vane be used, the wires before described are unnecessary, because cross-hairs can be fixed in the vane, and will become a substitute for the wires. The Heliotrope is in this case placed 2 or 3 feet in rear of the Sight Vane, and moved laterally and vertically, until the eye applied to the centre unsilvered dot, views the observer's station and the cross-hairs in one line. The Heliotrope must be secured in this position, and the means of doing so will readily suggest themselves. It is needless to say that it must be quite firm.

Final Observations.—The selection of stations is merely preparatory to the final observations, and is called an Approximate Series. It is usual to choose a few triangles in advance, and then detach a party to continue the Approximate Series, and prepare the stations ahead, while the final observations are progressing in rear. This division of labor is of great advantage in accelerating progress, and, if judiciously arranged with regard to local circumstances and the organization of the party, is productive of the best results.

The angles at a station are taken thus: Supposing the observer at A, and the signals at BCDE are all visible, the instrument is carefully levelled and adjusted, and so fixed that some station, B for instance, reads 0°, or zero; B is then called the zero station. Suppose the telescope to be brought up from the left hand of B, and turned gently, so that B may enter the field of view, and come near the centre wire, but not pass over it. Then clamp the instrument, and complete the bisection of B, by using the tangent screw of slow motion. Read off all the micrometers, or verniers, and let your assistant record the readings, in a fair legible hand, in the Angle Book. Look again into the telescope, and see that B remains bisected. If found correct, then carefully unclamp, and move the telescope gently towards C, taking care not to overshoot it. Clamp, bisect, and read off as before, and so on for D and E. You will thus have a complete set of observations at zero 0° observed by a continuous motion of the instrument from left to right. Now, overshoot the station E, and bring the telescope back by a continuous motion from right to left, observing each station in succession, and recording the readings. This will give a second set at zero 0°, which, if accordant, will suffice for that zero. It is the practice of the Trigonometrical Survey to make at least one repetition, in order that if mistakes creep in they may not pass undiscovered.

Now turn the telescope over 180° in altitude, and round 180° in azimuth, so that if the face of the vertical circle were previously to the left hand, it will now be to the right hand; B will then read 180°, and this is called zero 180° FR, the former position being zero 0° FL, *i. e.*, face left. Proceed as before, and take two sets of observations, the motion of the instrument being in one set continuous from left to right, and in the other from right to left, as before.

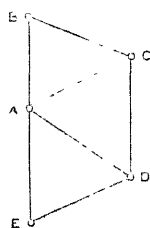
Having thus obtained four sets of observations for one position of the instrument, you will now, if the number of microscopes be three,* bring 10° under micrometer A, at which position you will get four other sets, and so on for 20°, 30°, &c., up to 50°, whereby you will obviously bring every 10° of the circle under one or other of the microscopes.†

* The Great Theodolites have five microscopes, and observations are taken at every nine degrees of the limb, by means of four change of zeros; the 18-inch and 24-inch have three microscopes

† Since this was written, Major Walker has suggested that although this method of changing zero

By this process you will have six changes of zeros and twenty-four readings, which will suffice for a complete set of angles, and you ought not to be satisfied with less, when carrying on work of primary importance. All operations in which these precautions are not duly taken, are considered to be of inferior order. This rule applies also to observations for azimuth taken upon circumpolar stars, which must always be taken at six zeros, or at every 10° of the limb at each elongation, as will hereafter be explained.

It has been supposed, in the foregoing instructions, that the signals at all the stations are simultaneously visible, which is not always the case. It is generally so when lamps are used at night, but when heliotropes are employed, it is evident that an eastern station will be seen with difficulty in the morning, whereas in the evening a heliotrope will shine vividly, and *vice versâ* in the case of a western station. Under these circumstances, the observations cannot be taken in regular rounds, in the simple manner before described. The best plan in this case is to use a point of reference, and connect each station therewith at such times as may be most convenient for observation.

The site selected for a referring mark should be such, that it may be visible at all times; its distance from the Principal Station should be from one and a half to three miles, and it should be nearly on the same level, in order that the elevation of the Telescope may be as little disturbed as practicable during the progress of the observations. It is also convenient that the situation of the referring mark should be central with respect to the circumjacent stations which have to be connected therewith. (*Vide* figure in the margin.)

In taking angles with the referring mark, it is often the case that the sets are observed by parts, but as it will not do to compose an angle of two parts taken at different divisions of the limb; therefore, you must be careful in taking

gives readings at equal parts of the limb round the circle, whereby the errors of graduation may be eliminated, there is no great change in the position of the axis, the defects of which may still affect the results. He proposes to obviate this by adding the arc between the microscopes to the arc by which the zero is changed. Thus, in an instrument with five microscopes, for five changes of zero the instrument will be set successively to

(0° 1′) (79° 12′) (158° 24′) (237° 36′) (316° 18′).

and for a three microscope instrument, with six changes, the zero will be set successively to

(0° 1′) (70° 12′) (140° 23′) (210° 34′) (280° 45′) (350° 56′)

By this method the axis will make nearly a complete revolution during the set of observations, and each angle will be observed at equidistant parts of the axis, as well as of the graduation. This alteration is therefore judicious, and should be carried out in future practice.

each supplemental part, to bring successively under microscope A the divisions which stood there when you observed the first part.

These two distinct parts, when assisted by addition or subtraction, may then be treated as a whole angle; for example, the angle BAC = the ∠ BAR − the ∠ CAR, and if the former angle be observed at a different time from the latter, then the reading of the point R should be the same, within a few seconds, at both times, so that the deduced angles may be composed of entire arcs of the limb of the theodolite in the same manner as if they had been directly observed without the intervention of a referring mark. If there be among the principal stations any one so favorably situated as to hold out every prospect of being at all times visible, it may be treated as a point of reference, and the other stations may, accordingly, be connected therewith, which will save the trouble of observing a supplemental point.

No good observations can be expected if currents of air are allowed to impinge on the instrument, or if it is subjected to the influence of solar rays, or any other causes calculated to disturb the equilibrium of the expansible materials of which an instrument is composed. Independent of this evil, it is also to be remarked that, if the wind is allowed to blow on the telescope, it frequently produces a lateral deflection to the amount of a few seconds. To protect the instrument from disturbing causes of this nature, it is sheltered by a tent, called an observatory tent, the observations being taken through small windows.

(To be continued).

No. CLX.

LAUNCHING GIRDERS ON THE JUBBULPORE RAILWAY.

Description of a Method of Launching Girders, practised on the Jubbulpore Line of the East Indian Railway. BY MIDDLETON RAYNE, ESQ.

THE girders to be erected on the Jubbulpore line were, (besides a number of small spans of openings ranging from 30 feet downwards,) fourteen of 110 feet, and six of 70 feet clear span, belonging to the following bridges:—The Semroul, of two 110 feet spans, at the 94th mile from the junction with the main line; the Sutna, of three similar openings at the 108th; and the Roharrie of one at the 165th mile; the Kutna, of three 70 feet, in the same mile; and the Newar, of three 110 feet spans in the 175th mile; the Hiran, of five 110 feet in the 201st mile; and the Parayet, of three 70 feet girders in the 217th mile.

The larger of these spans were lattice girders, of two systems, weighing complete about 97 tons; while the smaller were plate girders, weighing about 43 tons per span, both from the designs of Mr. Rendell.

In March 1866, Messrs. Waring, Brothers and Hunt, the contractors for the construction of the Jubbulpore line, undertook the erection of these girders, a work not included in their main contract. They stipulated for 12 months clear, in which to complete the work. Unforeseen delays in the delivery of the material having prevented their making a fair start till near the end of the year, they were urgently requested—and were themselves extremely desirous—to finish the work within the date of expiry of their main contract, the 31st of March, 1867. Great efforts were made

to accomplish this, and the measure of success achieved—though not complete—was considered satisfactory; a train having reached to within 50 miles of Jubbulpore on the 2nd of April, and having accomplished the remainder of the distance a month later.

The most important matter for the consideration of the contractors, was of course, the nature of the staging to be adopted, on which to build the girders, *in situ*; or the mode of getting them into place, if built in the bed of the stream, or elsewhere. The streams across which they were to be thrown, were all well defined and running between steep earthen banks; but the nature of their beds varied much—from rock and sand, to silt and soft mud. In all, excepting the Roharrie, water continued to flow during the whole year. The height from river bed to girder bed, varied but little in the various bridges, ranging from 40 to 45 feet.

In all cases, there was a want of anything like enough sand to make platforms in the waterways, on which to erect the girders, as was done so successfully at the Delhi Jumna bridge. Neither was timber of a suitable character for fixed stages procurable, except from great distances and at a ruinous cost.

Mr. George Nicoll and Mr. Mark W. Carr, the representatives in India of Messrs. Waring, Brothers and Hunt, therefore came to the conclusion, that for the deeper openings, at all events, some system of lifting the girders into place should be adopted. Two designs were prepared for carrying out these views—one by means of travelling stages, running across the river bed, near to the cutwaters—the other by means of heavy cranes upon the piers themselves. Both these were, however, rejected, in favor of a plan for erecting the girders in complete spans, upon the formation level of the railway, behind the abutments, and launching them across the openings one after the other, by means of traversing stages.

This plan was the more suitable for the occasion, that it admitted of the girders being fully erected behind the abutments, and ready to be put into place complete, at one operation; while the masonry on the piers, and even on the abutments themselves, where requiring it was being completed. Moreover, in this case of the lattice girders, the mode of attaching the cross girders to the bottom booms, would have rendered their being fixed at an elevation after the main girders had been separately lifted and placed, a matter of extreme difficulty.

Mr. H. P. LeMesurier, the Chief Engineer, having approved of the

plan generally, the writer was charged to carry it out with all possible despatch on behalf of the contractors.

But the complete plan for launching the girders across—if necessary—every opening of any particular bridge could not be carried out from want of time to make the necessary preparations. Where circumstances admitted it, the land spans were filled with earth; and as from careful calculations it seemed that the piers would be liable to be overturned by the pressure of this earth, they were protected on the inside by heavy counterforts of kucha brick work. The length of time, however, taken in filling such large gaps, prevented the earth being carried up to the full height, in more than one or two instances: the deficiency being made up by stacks of sleepers.

In other places, fixed stages were adopted, or rather attempted, temporary piers of masonry being employed in the absence of timber. Owing to the treacherous nature of the nullah beds, these all failed, more or less, completely, excepting in one instance where the success was complete. This was at the Sutna river, where the foundations for the temporary piers, about 42 feet high, were to rest upon some 12 feet in depth of sludge, that had been thrown out of the foundation wells and used to fill up a large hole in the river-bed at the site of the bridge. Into this mud-bed the writer saw a crowbar go overhead with very little more than its own weight after a few strokes had sent it through the upper crust. In order to spread the weight of the piers as much as possible, the whole length of the bay, about 45 feet in width, was covered with a layer of broken stone-ballast, 4 feet thick. Upon this three temporary piers were built, 5 feet 6 inches wide at bottom, and stepped in to 2 feet 6 inches at top; their bases resting upon a layer of timber 10 feet wide and 6 inches thick, to give them an extended bearing on the ballast. The masonry was flat bedded rubble set in lime, and the piers stood without a sign of a flaw; though in every other case where ordinary *pierre perdue* foundations had been used, failure followed, notwithstanding that the flow of water was trifling, and in every instance less than at the Sutna. It should be said that the stream ran freely through the interstices of the ballast and through depressions left for the purpose alongside each permanent pier. One or two small freshes occurred while the piers were in use, when the water flowed over the general surface of the ballast. Scouring was checked by throwing in rough rubble.

In all, five spans of 110 feet and two of 70 feet, were launched as about to be described; the remainder were built *in situ*, upon earthen banks, or fixed stages.

The girders that were to be launched were built behind the abutments, or piers, as the case might be, on a level platform of timber at a height of 3 feet 6 inches above the level of the masonry on which the cast-iron bed plates were to rest. This height was necessary to allow of trollies being afterwards placed beneath the bottom booms, on which to run the girder forward; so much would not have been necessary, but that the want of time to prepare special castings for low wheels or runners, compelled the use of ordinary railway carriage wheels.

In these trollies, as will be seen from the sketch, the whole weight—in order to save height as much as possible—was suspended below the axles; the beam bearing the girder clearing the rails by only about half an inch, and thus guarding against chance of damage through failure of any of the parts.

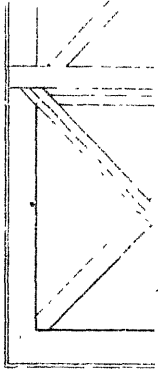
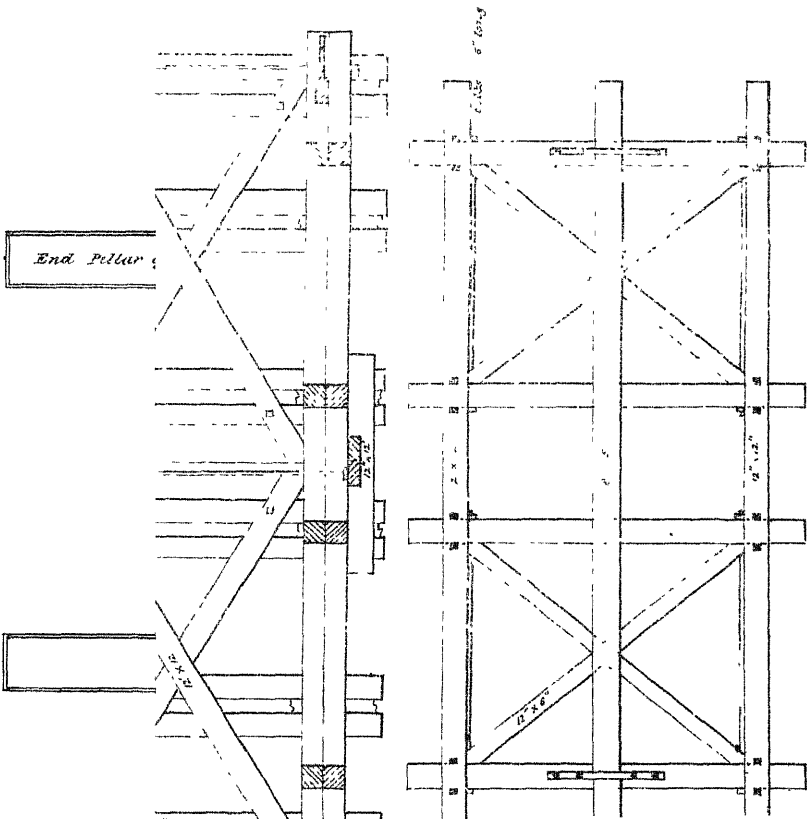
The front trollies were placed about 26 feet back from the fore end of the girder; so that when the whole was run forward, by the time they reached the edge of the abutment, enough of the girder projected beyond it, and beyond the travelling stage, lying close up to it, to allow of the girder being seated on its bed plates on the opposite pier, when the launch was completed.

The superstructure of the travelling stage was built of 1 foot square altic timbers, 30 feet long, securely braced, resting upon a massive framing of similar timbers, which again was supported by, and bound together, three parallel trucks, running each upon three pairs of railway carriage wheels; each truck of course having a separate line of railway.

The weight of the stage was taken upon both sides of the wheels—that is, both upon the journal outside, and upon the shaft inside, the nave. In the former case, cast-iron plummer blocks were used; in the latter, only pieces of plate-iron were needed to take the bearing.

The photograph, together with the drawing, will probably give a clearer idea of the structure of the stage than a written description.

In erecting the stage, it was intended to have run the girder forward first, so that it might be used as a jib with which to raise the frames. The backward state of the trollies prevented this, and the four frames, weighing each about 3 tons, and constituting with the braces, stages, &c., the superstructure of the stage, were separately raised by means of a jib of

GIRDERS ON THE JUBBULPORE RAILWAY
End Pillar
12"×6"
12"×12"

timber lashed to the lower boom of the girder and projecting some 10 feet beyond the masonry. As soon as raised, they were secured by means of the raking diagonal braces, by stages and tie-bolts; and finally by the three timbers lying across them all at the top; the middle one of these being the bearing beam, a piece of teak 18 inches by 15 inches by 30 feet long.

The whole weight of the girder carried was borne upon this beam, which rested upon the frames exactly over the apices of the main oblique struts. The object of this was to prevent any longitudinal undulations in the road from throwing the entire weight on the front or back sets of wheels, as might have happened had the beams above those wheels been loaded with only their fair share while the stage was perfectly perpendicular.

The whole stage was securely stayed with timber stays, and tied together with 1-inch and $1\frac{1}{4}$-inch through bolts, and was then remarkably rigid; so much so, that when carrying considerably more than half the weight of the girder—about 65 tons, indeed—and its own, about 35, it did not yield to the small, but unavoidable, transverse inequalities of the three lines of road. On the first occasion of its being used this was particularly noticed, when, for a short space, one of the outer pairs of rails being slightly low as compared with the others, it was observed that the truck running on that pair, did not descend to them for that space, but was borne along by the others; the wheels being clear of the rails and not revolving.

There being above 100 miles between some of the bridges at which this system of launching was to be employed, two stages were constructed—one at the Semroul and one at the Hiran. The first occupied a longer time than was expected in construction and erection—about 5 weeks—than was expected; the second—that at the Hiran—less than a month, including the four trollies, in themselves heavy pieces of work. An English sailor with a few ship's classies, was employed upon each stage, and they were found of very great service. After the first attempts, the men became accustomed to the work, managing the heavy timbers very dexterously; the whole of the launching operations having been accomplished without accident to life or limb.

The taking down of the stages for removal to another bay, was generally done in about two days, and the re-erection and placing of the trollies ready for another launch, in about 8 or 10 days more.

The first launch was fixed to take place on the 15th of February last, at the Semroul, when it was hoped everything would be in perfect readi-

ness. The front pair of trollies were, however, incomplete at the last moment; and as time was pressing, it was resolved to attempt getting the girder forward upon the traveller by means of heavy traversing jacks, at the front end—the hinder pair of trollies being in position. This was successful to the extent of about 14 feet out of the 26 required, when it became evident that the jacks—calculated for loads of 25 tons each—were unequal to the continually increasing strains. It was determined, therefore, to substitute rollers for them, there being at hand some admirably adapted to the purpose, belonging to the expansion bed-plates of the girders themselves; they were of cast-iron 2 feet 6 inches long and 7 inches in diameter, truly turned. Three rails abreast were bolted together through the fishing holes, and lashed to the under side of the cross girders, in the middle of each bottom boom of the main girders. A platform of timbers to the required height was then made; upon it were laid several rails upon the flat, and between them and the upper rails, a couple of the rollers, some little distance apart, were placed. The girder was then lowered upon these, and hauled forward the remaining distance with great ease, by means of a pair of double purchase crabs, each assisted by a set of double sheave block tackles, carrying half-inch chain.

When the girder was in position fairly over the traveller, wedges were placed between the bearing beam and the cross girder which had been arranged to come immediately above it; and in order to get the rollers out, the girder was lifted at the back end, there being no convenient position for the jacks at the front. After this had been done, and while lowering again upon the hinder trollies, a slight accident happened, which served to show the rigidity of the girders, and at the same time, the sufficient strength of the trollies. The jacks having been unfortunately placed on unstable packings, canted, and the girder got the amount of fall—about one inch—though in an oblique direction which the safety wedges admitted. No damage whatever accrued from this—except to the jacks—which were severely crippled.

On the following day the launch was completed successfully, the time occupied in hauling the travelling stage across the bay of 110 feet being three hours. In all succeeding cases, this operation was got through within an hour, including the numerous stoppages for "fleeting" the chain upon the crab-barrels. The power employed, in addition to the pair of crabs and tackles, already mentioned as attached to the girder on the top of the bank,

was another pair in the bed of the river, in every way similar, and attached to the travelling stage. These four crabs were simultaneously started and stopped by signals, given by the conductor of the launch, to which attention was called by striking a gong.

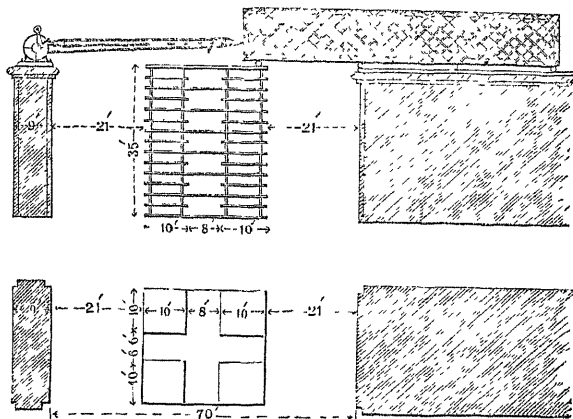
The Semroul girders having been launched before the large bed-stones, on which to rest the cast-iron bed-plates, were ready, the girder had to be supported in its elevated position, after the removal of the travelling stage and trollies, until they were prepared and put in place. As only 8 feet in the middle, between the two main girders, were available for the supports, from the room required for the placing of these stones, and as the end cross-girder was not calculated to sustain so great a stress accumulated near its centre, additional supports were obtained clear of everything, outside the girder, by lashing large beams across the end of it, projecting several feet on either side.

The stage and trollies had now to be removed to the Sutna—about 15 miles by kucha road—where two launches took place on the 16th and 28th March, respectively. They were then taken by rail and road to the Parayet, a distance of 110 miles, where it was intended by their means to launch two spans of 70 feet.

Owing to great delays in the transit, it became evident that this could not be accomplished within the date on which it was desired to allow an engine to pass to Jubbulpore—the 31st April—one month after the date of expiry of the main contract. Consequently, while one span was being travelled as usual, other means were devised for getting the second span into position. Four stacks of sleepers, one in each corner of a square 26 feet 6 inches by 28 feet on the sides in the middle of the bay, were built to the required height—in this case 35 feet, and bonded together at intervals of 5 or 6 feet by rails. This stage or temporary pier being 28 feet wide, left openings on either side, of 21 feet; the girder was hauled over on rollers —by means of a crab and tackles placed on the opposite pier—25 feet having been projected before hand to assist in building the sleeper stacks. The plan proved a very expeditious and economical one, for the class of girder on which it was tried.

The last span at this bridge was launched on the 27th April, and the road was laid across the bridge by the following evening ready to take a train across.

In the meantime another travelling stage, with all belongings complete,

had been built at the Hiran, where the two spans there requiring it were launched on the 3rd and 20th of April.

At the second of these launches, circumstances permitted the writer's arrangements to be carried out more completely than—from the extreme pressure of time—had been possible on any previous occasion. A short description of these may not be uninteresting.

The girder having been built on packings 3 feet 6 inches high by 4 feet wide, under each boom, the rails for carrying the trollies resting upon longitudinal balks, were enabled to be laid on either side of these packings, before disturbing anything. The trollies having then been put together in their required positions—after removing as much of the packings as was necessary to admit them—greased folding wedges were driven between the bearing plates of the girder, and the bearing beams of the hinder trollies; and as many of the wedges, upon which the girder had been built, as possible having been removed at the end next these trollies, a very slight lift with the jacks at the front of the girder sufficed to ease the weight on the remaining wedges so much that they could be struck. The sand-boxes on the front trollies having then been filled as full as possible—there being under the best circumstances, no more than 3 inches of fall to be got by them—the girder was now lowered upon their plungers.

The travelling stage being in readiness, close abreast of the masonry of—in this case—the pier, the girder was now hauled forward the requir-

ed distance. This, owing partly to a want of sufficient power in one pair of crabs and tackles, and partly to the small base covered by the front trollies, carrying so great a weight as 35 tons each, causing a sensible settlement of the roadway, was as usual, the only part of the proceedings that gave any trouble. When in its proper position over the traveller, folding wedges, well greased, were driven between the bottom booms and the plungers of sand-boxes resting upon the bearing beam of the stage; and by means of the sand-boxes on the front trollies, the weight was placed upon these—the second series of boxes. The front trollies having now done their work, were removed (in some instances they were lashed up to the girder and carried forward by it, being lowered afterwards by tackles into the river-bed, as in the instance when the photograph was taken); and the upper and lower lines of railway for the passage of the hind trollies and the traveller, being clear, the launch proper was proceeded with; and, as in each preceding case, was accomplished without the slightest hitch or difficulty; the stage moving with scarcely a perceptible vibration, even to those riding upon the girder. Large plumb bobs suspended from the top, and hanging over a mark on the lower, platform, showed but very trifling deviations from the perpendicular, laterally, but generally from 2 to 3 inches longitudinally, that is, in the direction of motion; there being invariably a tendency on the part of the stage to travel faster than the trollies—to be accounted for, as before explained, by the smaller base of the latter allowing of a greater depression in the roadway. The deviation mentioned showed no tendency to increase, and having established itself, it was not easy to reduce it by altering the powers at top and bottom.

The girder having arrived at its destination, with the bearing plates directly over the bed-plates of the piers, its weight was taken, by lowering with the stage sand-boxes, upon other sand-boxes placed upon the front pier bed-plates; these forming the 3rd series of boxes.

The traveller being now freed, was run back by hand—50 or 60 coolies managed it with ease—to its old position against the back pier. The sand-boxes upon it, having been refilled, and packings placed upon their plungers to such a height as would ensure their taking the weight of that end of the girder, while preventing its unnecessary rise, the front end of the girder was forthwith lowered into its permanent position on the bed plates by means of the pier sand-boxes; the tilt produced by this fall of 2 feet 6

inches at the front end of the girder, throwing the weight of the back end again upon the traveller, and freeing the hind trollies, which were at once removed. The sand-boxes from the front, having been brought to the back, pier, received the weight from the traveller, and the lowering into permanent position went on there as it had done at the front. Thus the whole of the launching operations, by help of the sand-boxes, involved only trifling jacking.

The actual business of lowering the girder into its permanent position, by the sand-boxes, occupied about two hours.

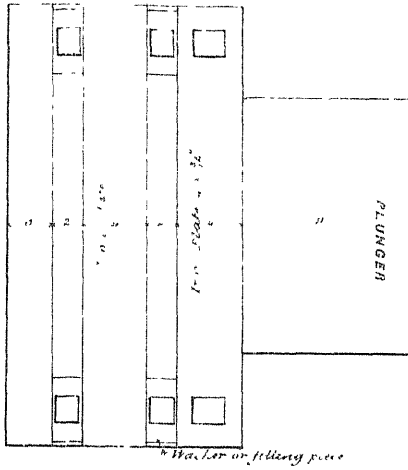
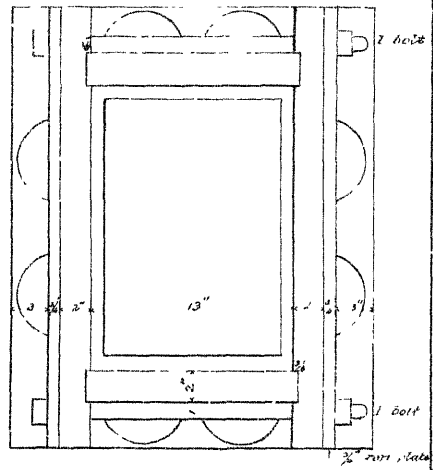
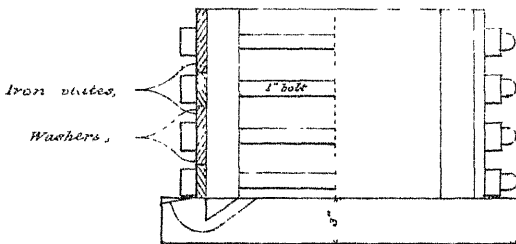
It was interesting to witness the accuracy with which the projecting end of the girder advanced and slowly took up its position over the bed-plates on which it was finally to rest; the discrepancy to be corrected was frequently not more than from $\frac{1}{4}$ to $\frac{1}{2}$-inch; nor was there any tendency to increase this during the lowering by the sand-boxes—the wheels of the traveller and the trollies being securely blocked. But, whatever the discrepancy might be, it was easily corrected by forcing the girder in the required direction by screw-jacks, after resting it upon the bed plates, these having been well greased first.

The method adopted of lowering by sand-boxes was very successful. The sketches of the three sizes used will be a sufficient explanation of the mode of construction followed. The writer believes the introduction of the cup at the mouth of the holes, to be of much advantage where great weights have to be dealt with. It offers great security against untimely movement of the sand, since nothing but a deliberate scooping out of that in the cups, will cause that within the boxes, to flow. The strongest gusts of wind fail to take an appreciable amount of sand out of these cups, even when entirely unprotected, while the same gusts will nearly undermine the plunger by sweeping through the space between it and the sides of the box. It also offers facilities for regulating the flow of the sand so as to ensure the plunger's descending perpendicularly—a matter of the highest importance in this case, where great weight, amounting indeed to half the weight of a span, or nearly 50 tons, had to be carried by the end cross girder, formed of a web plate, $\frac{1}{4}$-inch thick by 18-inches deep with a pair of 3-inch angle-irons top and bottom. It is obvious that a very small deviation from the plumb in the supporting plungers, would cause this frail member to buckle, as was unpleasantly proved on one occasion.

In deciding upon the proper strength and mode of constructing these

SAND-BOX

Scale 1 foot=1 inch.

12" 9' 6 3 0 1' 2 feet

boxes, doubts suggested themselves to the writer as to whether the description of box commonly used in easing centres, would be equal to the work on this occasion. The weight to be borne by each, varied from 35 tons on the trollies to 25 to 30, in other places; while the weight taken upon a box in lowering the largest centres can seldom reach one-third of these amounts.

It is not easy to see, theoretically, why extra strength should have been required, since the height of box adopted is hardly greater than that in common use. However, the results appear to have justified the doubts. When the weight of half the span was first placed on the boxes at the Semroul, and before any sand had been withdrawn, a very heavy strain was seen to be taken by the sides—they were bulged out about a quarter of an inch in their length of 18 inches; and as the lowering process went on, this appeared to increase with the smallest variations in the plumbness of the plungers, the wood frequently splitting and straining to an alarming extent. At last the heads or nuts flew off the bolts in one or two instances, and this was considered sufficient proof that more strength was required. These boxes were fitted at first with only thin bolts at each end—two others at each end were afterwards added. The straps were only $2\frac{1}{2} \times \frac{3}{8}$-inch.

The second lot of boxes, made for the Hiran, were fitted with 4 bolts at each end, as shown, and with $4 \times \frac{3}{4}$-inch straps. These stood well from the first.

The plungers first used were made of Baltic fir; but they failed utterly, the fibres crushing and sliding one upon the other. Any hard jungle wood was found to answer well. The boxes themselves were made of Maulmein teak.

The larger boxes gave a clear fall of about $9\frac{1}{2}$ inches, the smaller about 5. They were always filled brimful; the plungers rested on the sand at the level of the top of the box, the weight forcing them down from $\frac{1}{2}$ to $\frac{3}{4}$-inch. Each "fleet" of $9\frac{1}{2}$ inches occupied about two minutes, the loss of time occurring in shifting the boxes and in arranging the safety wedges, which were, in all operations of raising and lowering, so placed as to prevent the girder getting a fall of more than one inch, in case of accidents.

The cost of launching by this system is less than half that necessary in erecting a fixed timber staging even of common jungle wood, in this part of India. Were the complete system of traversing carried out as originally intended, by which the necessity of taking down the traveller

and re-erecting for each span, would be avoided, the writer believes that on bridges of, say 5 or 6 spans, this cost would be reduced to one-third. Of course the more the spans, the less would be the cost per span.

The system seems well adapted to cases where the height of the piers being from, say 40 to 50 or 60 feet, makes the filling in with sand or earth unadvisable, and fixed timber stages expensive: and also to those, where either the construction of the girder itself, or that of the bridge, presents difficulties in the way of lifting the span in separate ribs, over the ends of the piers, as is successfully practised on the G. I. P. line. There the great height of the piers—in some cases about 200 feet—would make any kind of staging difficult. But as their girders are so arranged as to carry the rails direct, there are no cross girders to be fixed afterwards, at a great elevation. Moreover, the piers there have no projecting cut-waters on the down-stream side—from which side the girders are lifted—a very important consideration where cranes or jibs have to be used.

It has the further advantage of allowing the whole of the girders of a bridge to be erected in a place of security, while the masonry works are in progress; thus not only saving the time that must otherwise be occupied in erecting the iron work, after the completion of the substructure, but allowing it to be done in a more leisurely and methodical manner than can be followed, when, as generally happens, a large girder bridge, unfinished, is the one link required to connect and utilise many miles of road.

On the subject of the erection and rivetting of the girders, the writer believes he has nothing of interest to relate. Men were drawn from Bengal, and from Oude and Delhi, besides those who could be procured in the North West. Many of them were old hands, and very expert rivetters, making work of a quality and neatness not to be surpassed. Fifteen to twenty gangs of six men each, were generally employed at a time on one of the larger spans, which they were able to complete in twenty days, when no delays from extraneous sources occurred. The better gangs would put in above 100 one-inch rivets in a day in plain work, but the average out-turn per gang, was certainly under half that number. Country hearths made of clay, each upon a plate of iron about 2 feet square by $\frac{1}{8}$-inch thick for convenience of portability, were used in preference to English forges, for heating the rivets.

Work at five bridges was in progress at once, upon each of which a first class European mechanic was employed, with generally a second to assist him.

During the passage of the first train with an ordinary passenger engine over these girders, the vertical depression averaged $\frac{5}{8}$-inch on the 110 feet spans, and $\frac{7}{16}$-inch on the 70 feet. The latter sprung back to their original position directly the train had passed, but in the case of the lattice girders, about $\frac{1}{4}$-inch was permanently taken out of the camber.

M. R.

No. CLXI.

CANAL DISTRIBUTARIES.

On the proper Alignment of Rajbúbas or Canal Distributaries. BY CAPTAIN W. JEFFREYS, R.E., *Executive Engineer, Ganges Canal.*

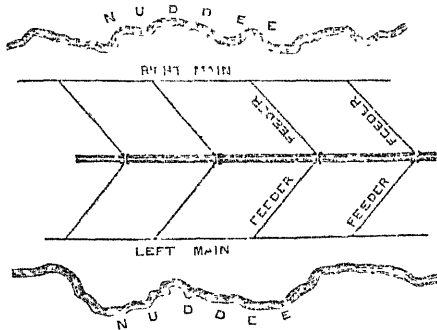
Naturæ non imperatur, nisi parendo.

BACON.

AMONG the several causes which have led to the COMPARATIVE failure of the Ganges Canal as a financial speculation, none has perhaps produced more prejudicial results than the defective alignment of the distributary channels. The main canal itself being a mere channel of supply, from which little or no direct irrigation is permitted, it is only natural to suppose that the defective irrigation must in a great measure be traced to faults in the construction of those channels which are more immediately intended for the distribution of water. And this is most assuredly the case. To explain the nature of these defects and to point out the only true principle on which works of this kind can be projected is the object of this paper.

It will be necessary to review the several methods on which minor irrigating channels, or as they are termed, rajbuhas, have hitherto been projected.

The first attempt that was made to bring this class of works under any recognised sort of system will be found in Sir P. Cautley's "Report on the Ganges Canal," para. 6, page 435, which is illustrated by the following diagram. It may simply be described as a series of feeders taken out from the

canal at an angle of 45°, and at equal distances; leading into one continuous straight channel on either bank, designated the east or west Main,

and parallel, or nearly so, to the canal itself. As all the bridges below mile 113 are furnished with masonry outlets for this object, it may be assumed that in the original system the feeders were intended to be from three to four miles apart.

The most obvious objection to it on a canal in which the surface of the water is below the level of the country (and experience has shown that it is unadvisable on sanatory grounds to retain large volumes of running water in embankment), is the impossibility of distributing the water by natural flow: for any advantage in command of level that is gained by taking out a channel above a weir, or by the difference, in slope of bed of the rajbuha and that of the main canal, must be foregone at the junction with the next feeder, where the bed must be lowered to suit the levels of the latter. As there exists moreover, throughout the entire country, an extensive ramification of natural drainages (some of them of large volume and extent), it is evident that any system of channels forced to take the direction shown in the diagram must cross and recross nullas and nuddees, the passage of which must be provided for, at a large outlay, by the construction of culverts and syphons. There cannot be the faintest pretence of following the watershed of such lines of drainage, and the channels must consequently often take a course unfavorable for the distribution of water through the higher land. This system is so obviously defective that it is now never employed.

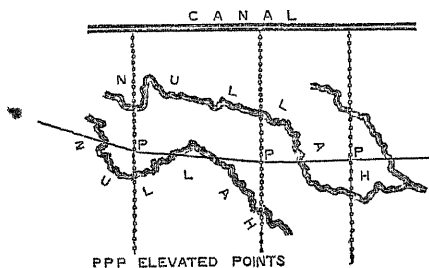
The worst example of rajbuhas constructed on this principle will be found on the right bank of the Etawah Branch, from miles 25 to 60 [*see Plate* LI.] In designing these lines, the Engineer entirely disregarded the drainages in that part of the country, which are very numerous and plainly defined, and the result is that jheels are traversed, sand-hills intersected, and nuddees crossed and recrossed in every direction: in fact no obstacles, however formidable, appear to have induced the designer to deviate from the

straight lines previously determined on. One of them, named the Jheyra Feeder, crosses five nullahs in a distance of four miles, necessitating the construction of three syphons for the passage of the rajbuha water under the drainage. The Right Main follows as nearly as possible the course of the Sirsa nuddee, which it crosses in no less than three places; and, notwithstanding the numerous syphons which have been constructed, the drainage is but imperfectly provided for, while in many places it is entirely intercepted. Over nine-tenths of the country thus intersected, irrigation is next to impossible, while in the remaining tenth it is attended with such drawbacks as to render it of doubtful utility.

Numerous other examples may be quoted in which the same characteristics are discernible, though in a lesser degree, and this must always follow any attempt to enforce a system of distribution, in which due regard has not been had to the physical conformation of the country and the features of the ground.

It is a leading principle in the construction of all irrigating lines that they should follow as closely as possible the course of the high ground on either bank, and to effect this, the plan generally adopted is to cover the tract it is proposed to irrigate with a series of cross levels a mile or so apart (time will seldom admit of their being taken at shorter intervals, while in many cases 3 or 4 miles apart is considered sufficient), and to connect the most elevated points by a line, which is henceforth adopted as the tracing of the proposed work.

Judging by the numerous examples that everywhere abound in which the proposed result is certainly not attained, it becomes our duty to enquire how a system so apparently sound should fail in securing the end in view?

The fact is, that owing to the numerous nullahs and drainages that intersect the country, there may often be found two or more lines of water-shed parallel, or nearly so, to each other; and unless the principal features are carefully delineated on the map, the Engineer is apt to confound one watershed with another; so that while he is under the impression that he is following one, he is in reality connecting two entirely different

watersheds, the connecting line, as is often the case, following the course of the intervening valley. The above diagram will illustrate the case in point.

A remarkable instance of this may here be mentioned. In 1860 a new line for the Delhi Canal was designed on an elaborate system of cross levels taken at a mile apart, and a project was drawn up on the most approved principles. The Punjab Government however directed that a survey of the drainage should first be made, and the writer has since been informed by the officer engaged on the work, that the proposed line which fulfilled all the necessary conditions in the original scheme is now found to cross several important lines of drainage, and to be about the worst that could have been selected.

In order to deliver the water under the most favorable conditions, it is clear that irrigating channels must everywhere follow the watersheds of the country drainage. The first step then is to ascertain how many features of this kind exist, their extent and relative situations. This knowledge can only be acquired from a careful survey of the country it is designed to irrigate, care being taken to delineate on the map the course of all rivers, nullahs and streams, and the position of all hollows and jheels. To each watershed should then be assigned a separate channel of a capacity apportioned to the duty it has to perform, the two bounding streams or nullahs being considered in this system as the limits to which irrigation from any single line should be carried [*Plates* L. and LI.]

Having then traced out on the drainage survey map the general course of the proposed channels, it may be found necessary to run two or three lines of cross levels in such places where, from absence of all drainage features, a doubt may arise as to the exact position of the watershed. With the aid of the information thus obtained the Engineer will be enabled, *after a careful examination of the ground,* to fix on the precise trace of the proposed lines.

For the more complete and efficient distribution of the water, branch-lines (or as they are termed minor rajbuhas), should be taken out from the main or principal channels where they may be most required; but the Engineer should in a measure be guided by the nature of the ground and the character of the soil. As in the case of larger works, he should endeavour to secure a command of level for the purpose of affording every facility for irrigation: He should avoid as far as possible crossing minor drainages or

stumbling into hollows by which his object may in any measure be defeated: He should banish from his mind any idea he may entertain of the relative unimportance of this class of works; for he may be assured that nothing tends so directly to an economical distribution of the water as a carefully constructed system of minor rajbuhas.

Thus a principle is established which is susceptible of universal application, whether the works to be designed are of the greatest magnitude or of the smallest pretensions. Though sufficiently understood in the alignment of large canals, it has been too much ignored in the projection of minor channels, to which must in a great measure be attributed the difficulties that attend the distribution of the water.

It may help us to arrive at a due importance of the subject by considering some of the prejudicial results that must follow neglect of the rule laid down. These evils will be induced in a greater or less degree in proportion to the extent to which the principle is violated, and may be enumerated as follows:—

I. Greater original outlay on high embankments, the construction of which might have been avoided.

II. Additional yearly expenditure on maintenance and repairs.

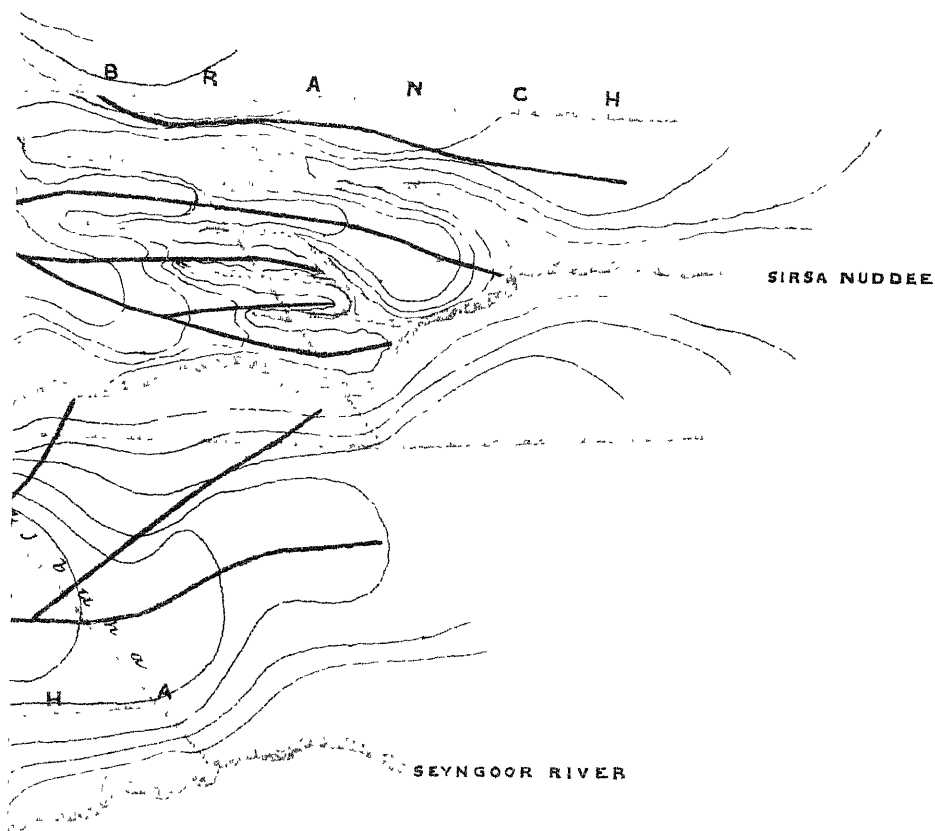
III. Unfavorable position for the distribution of water through the higher lands.

IV. Consequent loss of revenue.

V. Intercepted drainage.

No one can inspect the irrigation channels on the Ganges Canal without being struck by the enormous expenditure incurred in many places on the construction of high embankments, the necessity for which would never have arisen had the lines in the first instance been judiciously selected; and the unfortunate part of it is that all this additional outlay is in no way compensated for by any increase in efficiency. It does not require much to show that the reverse must be the result: for where a line of watershed is departed from, it will be necessary, in order to irrigate effectually the higher lands, to keep the smaller field water-courses on the same high level as the channel of supply, which in practice is almost impossible, owing to the construction and maintenance of these works devolving on the cultivators, who can never be persuaded to bestow the necessary amount of labor for this object.

But it is from a sanitary point of view that the matter is deserving of

B R A N C H
SIRSA NUDDEE
H A
SEYNGOOR RIVER

the gravest consideration. Much has been said and written on the importance of securing a thorough system of drainage in all districts under the influence of constant irrigation. The frightful evils that have resulted from the absence of such measures in the districts bordering on the Western Jumna Canals are too well known to need any lengthened notice here, but as in all cases *prevention is better than cure*, so the first step should surely be to interfere as little as possible with the existing natural drainages of the country. The Engineer will then have no artificial obstructions of his own creation to contend with, in carrying out a system of drainage operations at any future period.

Before closing this paper, it will be necessary to say a few words on the system advocated by most Canal Engineers of tailing one irrigating channel into another, with a view of preventing waste and ensuring a greater economy in the distribution of water; the idea being that the surplus water from one rajbuha may be passed into the next and thus utilized on irrigation, instead of being allowed to escape into nuddies. It is presumed, of course, that this is only applicable to periods of diminished consumption; for, systematically to pass down at all seasons a certain quantity through long and roundabout channels to feed others that might be supplied direct from the canal, is a manifest waste of water. Except in the upper portions of the canal it may generally be assumed, for obvious reasons, that the supply is inversely proportionate to the demand; whenever a slight cessation in irrigation takes place, the supply in the canal immediately rises, the influence of which is felt in all the minor channels. The question is, whether at such times the addition of the surplus or tail water of one rajbuha to the already increasing volume of another would prove any boon to the cultivators. The writer has seen no advantage gained by this arrangement, but has often found it give rise to serious inconvenience.

It is to results, however, that we must chiefly look for the real test of the comparative advantages of the two systems. Waste is properly defined as expenditure without an equivalent, and as the irrigating duty of water is now fairly known, the actual waste in any channel can be approximately found by comparing the areas irrigated with the average working discharge. Taken by this test it has been found that the large self-feeding rajbuhas, unsupplemented by other lines, show the largest and most profitable returns; and, consequently, the supposition that the tailing of one

irrigating channel into another is productive of greater economy is not borne out by actual experience.

In the system advocated by the writer, the capacity of an irrigating channel should everywhere be exactly apportioned to the duty it has to perform, the section decreasing as the line advances, until it loses itself in a small village water-course. A large margin should be allowed for further possible development of irrigation.

Escapes will be required at every 8 or 10 miles, but they should only be resorted to on emergencies, it being preferable to reduce the supply by partially closing the gates at the head.

It is scarcely necessary to point out the principal considerations that should guide the Engineer in the construction of works of irrigation. Economy in original cost is perhaps the most important. It may seem like a truism to say that no work, however efficient it may ultimately become, can give a fair return upon the outlay, where a reckless disregard of economy has been exhibited in its first construction; and yet the numerous examples that everywhere abound show that this axiom can scarcely be too strongly insisted on.

By following the principles we have endeavoured to explain, it is quite possible for the Engineer to realise at one and the same time the two most essential elements of success, *minimum of cost* and *maximum of efficiency*, while the first step towards reducing to a minimum the evils attendant on irrigation will have been secured. It is only by adapting the system of distribution to the natural physical conformation of the country that this result can be attained. That principle cannot be better described than by repeating the maxim, which stands at the head of these pages, "that nature can be controlled by obeying (and only by obeying) her laws."

W. J.

No. CLXII.

RESERVOIRS FOR THE DAMOODA RIVER.

Report by LIEUT. H. W. GARNAULT, R.E., *of his exploration of the Upper Reaches of the Damooda River. Dated 24th June,* 1864.

IN Government of Bengal's letter of the 30th October, 1863, I was ordered to explore the heads of the Damooda and Burrakur rivers, with a view of finding sites suitable for reservoirs to hold the surplus water which inundates the country in the lower reaches of those rivers.

Owing to unavoidable delays I was only out about two and a half months and during this time I took a longitudinal section of the bed of the Damooda from its junction with the Burrakur to Ramghur (a distance of 100 miles) and 13 cross-sections; besides this, I reconnoitred four very suitable sites for large reservoirs and several smaller ones,—a full description of which I shall give hereafter.

The country through which my route lay is very difficult. From the Jumooneah Nuddee (the boundary of the Hazareebaugh district) to Ramghur, it is one mass of dense jungle and rocks. The few villages that exist are of the poorest description, consisting of two or three Sonthal huts, so that I experienced great difficulty in finding ground for encamping anywhere near my work, and was often compelled to send to great distances to obtain the bare necessaries of life for my camp.

Accompanying this Report are the following plans and sections:—

1 map of the basin of the Damooda and Burrakur rivers.

1 longitudinal section of Damooda from Ramghur to its junction with the Hooghly.

8 cross-sections of the Damooda (3 only printed).

Of the section, the portion from Ramghur to junction with the Burrakur was taken by myself; the portion between the junction with the Burrakur and Raneegunge, I have put in approximately from the Railway levels; and that between Raneegunge and junction with Hooghly is from an old record in my Office, the levels of which were, I believe, taken during my predecessor's incumbency of the Division. I closed with the Railway levels at Burrakur, and took their datum, namely, the sill of Howrah Dock, but I have since reduced all the heights to mean sea level, allowing the latter to be 11·63 feet higher than the sill of Howrah Dock, according to the Great Trigonometrical Survey calculations.

In making calculations of the discharge of the river, I have used Eytelwein's formula, viz., $D = \cdot 9 \sqrt{2 fd} \times s$, where $D =$ discharge, $f =$ fall per mile in feet, $d =$ hydraulic mean depth, and $s =$ area.

I have marked on my sections the flood of 26th September, 1863. Mr. Powell, Executive Engineer, was kind enough to drive in pins at the limit of the flood at two or three places near Burrakur; and in the higher reaches of the rivers, I have taken the marks on the banks: where no marks were visible, I have obtained the height from the villagers. I have assumed this flood to be a maximum; and the rain-fall which caused it, a maximum rain-fall in 24 hours over the catchment basin.

These assumptions will, I think, give very safe data for determining the size and number of the reservoirs required, as the rain-fall recorded at Hazareebaugh, on 25th September, viz., 13 inches, is 5 or 6 inches more than any fall hitherto recorded; and the flood of September 26th rose higher and lasted longer, in the lower reaches of the river especially, than any previous flood since the memorable one of 1823.

The flood of 1823 must have been extraordinarily high: the marks of it have been pointed out to me from Cowcolly Light-house to Ramghur, and it appears to have been at least 10 feet higher than any that has since occurred. In this flood, however, the Damooda and all the other rivers in Lower Bengal were held back by the very high sea-wave which came up the Bay and caused such destruction to life and property along the coast south of the Russoolpoor River.

Before describing the reservoirs, I propose giving a sketch of the Damooda river from its source.

The Damooda, or Deonud, as it is called in the higher reaches of the river, rises in Toree, about 50 miles south-west of Hazareebaugh, and 40

miles north-west of Ranchee; it flows in an easterly direction through a wild country between high rocky steep banks covered with jungle, and over a sandy and rocky bed; the fall appears to be about 6 or 8 feet per mile as far as Ramghur.

From Ramghur to the south of Gunkee, the river still runs in an easterly direction, and through similar country; the bed, however, is more sandy, and the fall is 6·56 feet per mile.

From Gunkee the river takes a northerly course to Julla or Mirzapoor, and the fall is considerably increased, being to Gugree 17 feet 5 inches, to Gaga 10 feet 8 inches, and to Mirzapoor or Julla 14 feet 9 inches, per mile. The bed has several small breaks, and is a mass of huge boulders, which show unmistakeably the terrific velocity of the river when in flood. The banks are very high, rocky, and covered with dense jungle.

Between the junction of the Bhera Nuddee and Gugree there is a hole, or "*dhow*," in the river, for a length of a quarter of a mile, which is said to be unfathomable: the dry weather stream here is about 20 feet broad, and runs between perpendicular rocks about 18 feet high; these rocks are themselves covered in floods.

At the angle formed by the junction of the Bhera Nuddee with the Damooda, there is a stone temple (Rajarapar mut) built by one of the former Rajahs of Echak, and ministered to by a family of Brahmins who live at Hishapoora; the plinth of this temple was above the flood of 1863, but I was informed that the flood of 1863 rose up to the top sill of the doorway; it also lifted some of the stones of the steps and basement (about 8 cubic feet each), and deposited them 20 or 30 yards distant.

From Julla to Tureeo the river again runs east, and with a fall of from 5 to 6 feet per mile; the bed is principally of sand, with rock cropping out here and there: the banks are high, and a large quantity of coal is visible in them. From Julla, the timber cut from the Ramghur Hills is floated in rafts to Tureeo, where it is landed and conveyed by cart to Rungamattee; here it is again embarked, and can proceed without impediment to Calcutta by the river.

Between Tureeo and Rungamattee there is in 3 miles a fall of 100 feet, or about 32·49 feet per mile; the bed in this portion has several breaks, and is a mass of huge boulders lying about in most bewildering confusion. Opposite Rajabera there is another "*dhow*," or deep hole, similar to the one at Gugree, already described.

From Rungamattee, or the Jumooneah Nuddee to its junction with the Gowaie, the river takes an easterly course, and has a uniform fall of about 4·5 feet per mile; the bed is sandy and rocky, and the banks are high and and almost entirely of rock. Just above Tasra for some distance they have the appearance of having been cut to a regular slope of 2 to 1. The high flood line is very distinctly marked about ¼-inch up the bank.

From Tasra to Raneegunge the slope of the bed is from 3½ to 4½ feet per mile, the banks are lower, very little rock appears in the bed; and the width between banks increases considerably.

From Raneegunge to opposite Burdwan the slope is about 2½ per mile; the bed is broad and sandy—the banks are low and alluvial. From Burdwan to Champadanga the fall is 1½ feet per mile; and from Champadanga to junction with Hooghly about half foot. From Amptah the Damooda becomes tidal.

From its rise to its junction with the Hooghly, the Damooda has altogether a course of 337 miles in length.

The principal tributaries of the Damooda are the Chundro or Gurhee, the Haharoo, the Suphee, the Koonare, the Jumoonah, the Gurgee, the Khatree, the Gowaie, the Burrakur, and the Singaron.

The whole area drained by the Damooda is about 7,600 square miles, of which 6,900 is drained just below its junction with the Burrakur. From Seilnah, or about 96 miles from its junction with the Hooghly, the river is embanked and receives little or no drainage.

In order to obtain some knowledge of the proportion of rain-fall which is drained by the river, and that which is lost by evaporation, absorption, &c., I propose making a comparison between the rain-fall of September 26th at Hazareebaugh, and the water that passed through the river at certain sections; the result will not of course be perfectly accurate, as I am dependent on the statements of the villagers for the duration of the floods; and the measure of the rain-fall is not, I think, as accurate as it might be on account of the rough instruments used in determining it.

The discharge too, is not perfectly accurate, as it has been calculated from the dry weather section of the river; there is a great deal of sand in the bed of the river now which could not possibly have existed when the river was in flood, so that the depth, and consequently the discharge, is less as here shown than it must actually have been. There is, however, to a certain extent a set-off against this error, as it is more than probable that

ɟfore the flood came down, there was some water in the river, of which I ıve taken no account.

The sections which are, I think, most to be relied upon, are Nos. 1, 4, ıd 8, viz., those at Ramghur, west of Gurgee Nuddee, and above the junc-on with the Burrakur. At the latter, the flood limit was marked by Mr. 'owell himself, and the two former sections were taken at the crossings f the Hazareebaugh and Ranchee, and Govindpoor and Ranchee roads, espectively, where the heights of flood were well known. I shall use hese three sections therefore in comparing the proportion of rain-fall lrained by the river.

At Ramghur the discharge per second was 102,239 73, and the flood is said to have lasted two and a half days; the whole amount of water, therefore, that passed through the river was 22,083,781,680, which is about $7\frac{1}{2}$ inches of rain over the area drained, viz., 1,000 square miles.

At the section west of Gurgee Nuddee the discharge was 194,218·47 per second; the flood lasted three days, and the water that passed through the river was 50,341,427,424 cubic feet, which is equivalent to 7·2 inches of rain over the area drained through that section, viz., 3,000 square miles.

At the section above the junction with the Burrakur, the discharge was 284,388·7 cubic feet per second; the flood is said to have lasted three days; the water that passed through the river was 73,713,551,040 cubic feet, which is equivalent to 7·5 inches over area drained, viz , 4,200 square miles.

The rain-fall that caused the flood under consideration was 13 inches, and from the above calculations we find that 7·5 of this were drained by the river; the remainder being lost in evaporation, absorption, tanks, &c., $7\frac{\frac{1}{2}}{13}$ or $\frac{2}{3}$rds say, is the proportion of rain falling on the catchment basin which passes through the river, and this is the proportion which the reservoirs must be capable of holding, whether they are constructed to shut off a weekly, monthly, or yearly rain-fall.

As the first object of the reservoirs is to save the country below from inundations which only occur three or four times a year after an unusually heavy shower of rain on the catchment basin, it will be sufficient to construct them capable of holding the greatest monthly fall: the floods run off so rapidly that ample opportunities would be afforded of emptying the reservoirs when the river is low, and so keeping them ready for receiving the next heavy shower; the last month's rain of the season might be retained in the reservoirs, either for the purposes of irrigation or for feeding canals.

In Appendix B., I have entered all the inundating floods that have occurred during the last five years, as shown by the Edilpoor gauge; when the flood rises up to 10 feet on this gauge, it tops the right bank. From the time that elapses between two consecutive floods, it will be at once seen with what facility the reservoirs might be emptied.

In Appendix A., the rain-fall for each month, during the last five years, is recorded; the maximum in any month is 31·13; the reservoirs must be capable of holding two-thirds of this, or 21 inches over the whole area whose waters they receive.

The most suitable sites for reservoirs which I had time to examine are on the Gurhee, Haharoo, Konare, and Bokaro Nuddees. In speaking of these streams, I shall use the names given on the Revenue Survey Map, although they alter their names in each village through which they run.

The Gurhee is formed by two or three small streams which rise in the Kasiatoo and Joradug Hills; the last it receives is the Choondroo just above the town of Tendwa. In the mouth of the Choondroo there is an extraordinary natural bar of rock, through a fissure in which, the stream runs. Opposite Tendwa the Gurhee is about 5 chains broad and has very high sloping banks. About 5 miles below Tendwa, it runs between the Niree and Chiloomaree Hills, whose summits are less than a mile apart; the dam for the reservoir might be constructed in a line between the villages of Utratoo and Chiloomaree.

The drainage of 185 square miles passes through the Gurhee, so that the reservoir would be required to contain (supposing as I have said before that it is to hold the available maximum monthly rain-fall) 7,736,256,000 cubic feet, and it would cover an area of 6 square miles, and be on an average 48 feet deep; the valley through which the stream runs below Tendwa, and before it enters the gorge between the hills, is more than a mile broad and deep, so that there would be ample space for this water, the stream itself too would be ponded up for 3 or 4 miles. The valley is principally grown over with short scrubby jungle, and the only villages that would be destroyed merely consist of a few Sonthal huts.

The Haharoo, which is the site of the next reservoir, is formed of the Sikree, Gulgullea, Bukwa, and Badmahee streams, all of which rise in the Hazareebaugh plateau: the Haharoo runs close under the Mondee Hill, and then passes through a gorge about half a mile wide between the Acharoo and Angoo Hills—the former being as it were a continuation of the

Mondee Hill; this would be a suitable site for the dam. The Acharoo and Angoo Hills are almost perpendicular for three-fourths of their height from the top, and then they slope gradually to the banks of the Haharoo, which are very steep, and about 20 feet above the bed.

About 250 square miles of drainage passes by the Haharoo to the Damooda, so that the reservoir would have to contain about 10,000,000,000 cubic feet of water, and cover an area of 7 square miles, with an average depth of about 53 feet; the valley above the dam, and the beds of the streams themselves would, I think, give us this area, but apart from this it would be quite possible to relieve the large reservoir by forming small ones on each branch of the stream before they unite. I went up the Badmahee to its source, and saw two or three such sites where a dam of 100 feet long only would be required. The smaller reservoirs would be more advantageous for irrigation, being situated higher up the valley, but it is just probable that the cost of three or four small dams, and one moderately sized one would exceed the cost of the large dam in the Haharoo itself.

By the Gurhee and Haharoo reservoirs the discharge of the Damooda at Ramghur would be reduced by about one-third.

The third reservoir would be formed by the Bokaro, which rises south of the Hazareebaugh plateau, flows easterly through the Lugie and Jollinga Hills, and joins the Konare about 4 miles west of the junction of the latter with the Damooda. A very suitable site for a dam would be about 2 miles east of Lalghur, where the gorge between the Lugie and Jelinga Hills is not more than 1,000 feet broad. The Bokaro drains 225 square miles, the reservoir would have to contain 9,400,000,000, cubic feet of water, and would cover an area of 7 square miles to a depth of 48 feet. Before passing between the Lugie and Jelinga Hills south of Leyo, the valley is very broad, and there would be no difficulty in stoiing this water: the villages on the banks of the stream where it enters the gorge, such as Lalghur, Dhundunya, &c., would be destroyed, but although they appear to be large villages from the map, they consist of two or three Sonthal huts only; the valley is of jungle, which is very dense between the hills.

The fourth reservoir would be on the Konare: the denseness of the jungle, and my sudden re-call to Burdwan pervented my making as complete an examination of the site for the dam as I could have wished, and as I made at the other sites; but a dam might be constructed between the Pureary Hill, which is a continuation of the Jelinga, and a ridge to the

north of the Konare which runs along the left bank of Konare and Damooda. The Konare carries the drainage of 550 square miles of country; it would be necessary to store 20,000,000,000 cubic feet of water; this might be retained in two or three reservoirs one at the site above described and others higher up the stream.

With these four reservoirs the discharge of the Damooda just above its junction with the Burrakur, would be diminished by two-sevenths of the present discharge per second.

I have marked on the map the sites of the dams and the probable area and position that the water would occupy. I am unable to give approximately the cost of constructing the reservoir dams, but the sites are so favorable, and good stone for building so easily obtained at each site, that I would recommend the necessary sections being taken, so that estimates might be framed for two of the dams at least, and from these some idea might be obtained of the probable cost of the whole projects: the sites which would offer least obstacles for surveying and levelling would be the two westernmost reservoirs, viz., those on the Gurhee and Haharoo: the levels for these would probably occupy a good surveyor about six weeks.

The reservoirs that I have already described would not, of course, be sufficient to save the country south of Burdwan wholly from inundation but they would of themselves lower the flood level at Edilpoor by more than a foot, and of the 30 inundating floods that have occurred in the last five years, 15 would have passed innocuously down through the bed of the river and the danger caused by the remainder would have been greatly alleviated, probably sufficiently so to have allowed the villagers to stay in their huts, instead of living for two or three days in trees as they were compelled to do during the flood of September 1863.

The system of reservoirs is not unknown to the natives of the district, as on the road from Tendwa to Hazareebaugh, just below the Doongree Ghât, I saw a dam, which a Zemindar has constructed for irrigation, across the Dinia Nudee, where it issues from the hills. The dam is strongly built of stone and brick about 100 feet long, and 30 feet broad at top: there was, when I went over it on 19th March, a head of 6 feet of water on the upper side.

In the Maunbhoom District, on the left bank especially, there are numerous small streams (locally called "jhoors") which rise a little south of the

Grand Trunk Road, and run due south to the Damooda, carrying the drainage of about 10 or 12 square miles. These could all be very easily and cheaply dammed before they empty themselves into the river: the water thus retained, while causing a diminution in the discharge of the river, would be very beneficial to the country for dry weather crops; the ryots when spoken to on the subject readily admitted the advantage, but the universal question was, who is to pay for the dam? Until the ryots, instead of being possessors, are simply cultivators of the land, such improvement by private individuals must not, I suppose, be expected. Of some of the larger of these streams which could be most easily dammed for reservoirs, I may mention the Gheejhoor, Kalajhoor, and Kaseajhoor.

After my survey during the ensuing cold weather, I feel sanguine of being able to point out more sites equally favorable both on the Damooda and Burrakur, which will enable us entirely to control the floods in the river, and at the same time afford means of irrigation to a country which is at present uncultivated for want of water. Now, that the tea producing capabilities of the Hazareebaugh District have been established the land bordering on these mountain-locked lakes will become very valuable, and the proceeds of the sale of the water for irrigation will go far towards covering the expense of the dams.

H. W. G.

Memo. by LIEUT.-COL. SHORT, R.E. *Superintending Engineer.*

If the freshes in the Damooda only had to be dealt with, there would be no doubt as to the advisability of forming these reservoirs; more especially as several other, though smaller, sites could be found on a more thorough examination of the country, but the point is, to what extent the formation of these would affect the level of the combined flood of the Damooda and its tributary—the Burrakur, at Edlepoor, near Burdwan.

Lieutenant Garnault states that the flood level at Edlepoor, near Burdwan, would be lowered more than a foot, and he shows, that of the 30 inundating floods which have occurred during the last five years, 15 would have passed innocuously by this decrease of one foot in level, and of course the remainder would have been alleviated.

This testimony to the misery endured during seasons of excessive flood by a population scattered over such an extensive area, shows the absolute

necessity of endeavoring to alleviate their sufferings which are intensified by the uncertainty as to the course the spill-flood may take. The country bordering the right bank may be said to be undulating—the villages being situated on the high ridges—the flood passing through the intermediate valleys. The fluctuation in the volume of spill escaping through these numerous hollows is remarkable—in one season the waters flowing at one locality 500 feet broad and 6 feet or more deep—and as they fall filling the low level with sandy deposit; the next year's flood forsaking the passage and creating a similar escape above or below. These vagaries of an uncontrolled flood threatening one village this, and an other the following, year, naturally serve to keep the population scattered over the inundated area in a state of panic.

As each case of danger to a village community is taken up on its special merits by the Government in a humane and liberal spirit, and orders are given to protect the locality by embanking against direct spill, the natural consequence is, that the flood is thrown the next season in excess on the villages above or below, and these in their turn claim equal consideration; and if similar action continues to be taken, the free spill ordered to be provided over a certain length of the right bank will be gradually and almost imperceptibly interfered with; moreover, this system of detached embankments only forces the spill to pass with greater velocity through the intermediate escapes, thereby scouring the country, and forming numerous escape channels, all which cut up the bank and country, and tend to increase the panic in the interior.

It is true that the uncertainty to life and property is not great in the Burdwan district, as there are but 96 square miles inundated; but the spill soon passes into tbe Hooghly district, wherein 264 square miles are flooded, the level is much lower, and the inundation intensified by the freshes being held up on all occasions of simultaneous high springs.

It has been recorded by the late Superintendent of Embankments that the battle with the Damooda has been fought and won; but dealing with the question in all its bearings, and with greater opportunities afforded to judge of results, and above all, studying the interests of the Government and the country, I venture respectfully to differ, believing as I do, that the battle is an annual one, and that embanking continuously on the left bank and forcing the excess flood over the right, has produced the undermentioned results:—

1st.—The embankment on the left bank is but very slightly tried, the flood rising thereon but a few feet.

2nd.—The absence of scour in the lower reaches has so deteriorated the channel, that the coal traffic has been closed; that is, whereas Amptah, situated about 40 miles above mouth of river, was the great coal depôt, it has been abandoned, as large boats could no longer navigate the river.

3rd.—The decreased scour in the channel along the portion where free spill has been provided has caused a deposit in the bed, which is being gradually raised in level.

4th.—Insecurity to villages owing to vagaries of an uncontrolled flood, which entails endless petitions and necessitates re-construction of detached embankments, which interfere materially with the full escape considered necessary.

5th.—The great and increasing danger to the country to the south of the Buxee Embankment (situated between the Damooda and Roopnarain rivers) owing to the spill-flood of the Damooda standing during an extraordinary season of flood at an average height of $11\frac{3}{4}$ feet on the section for a period of two and a half to three and half days until escape is found *viâ* the Roopnarain river—such a test being excessive.

6th.—The erosion that has taken place in the Roopnarain river below the head of the Buxee Khall, and which may be expected to continue, owing to the action of the excess volume now gorging the Roopnarain channel, has demanded retired lines, and now a further considerable retirement is necessitated, all which remedial measures entail outlay and loss of property.

7th.—There is always the probability of the floods opening out on the right bank a channel similar to that at Kistopoor or Sreekistopoor (both closed at considerable expense), and escaping in volume southwards, when the consequences would be serious.

8th.—In proportion to the deterioration of the channel of the Damooda to the south within tidal influence, will be the decrease of volume passing up, and therefore a consequent loss of the power exercised by each ebb in scouring out the Hooghly at a most important point; and as the efficiency of a tidal channel is doubtless maintained by the volume ebbing in the channel itself and in the several tributaries, the deposit of sand at the mouth of the Damooda will yearly gradually increase to the detriment of the Hooghly.

9th—The deterioration of the channel of the Damooda below Ranegunge and the difficulties in its navigation are yearly increasing, as experienced by the Coal Companies, and as the rail cannot compensate for this, the prosperity of the Coal Companies is affected.

10th —Ten years ago since, the mouth of the Roopnarain, or rather the narrow clay-bound neck, was some 2,500 feet only broad between the embankments and 2,500 long, and the section has been slowly but imperceptibly enlarging, entailing retired lines. Any disproportionate enlargement of this neck would be a most serious matter, for being in direct continuation of the Diamond Harbour Reach, the tides would pass in excess up the Roopnarain to the detriment of the Hooghly Channel; and as the volume at ebb in the former would be in excess, that in the latter would be held back, thereby increasing the tendency to the formation of shoals from deposit.

I venture to point out the difficulties to be contended against, because I am convinced that the whole would be overcome could the excess flood be stored in reservoirs. I would, therefore, strongly recommend that some one specially adapted for such work be appointed to visit the country immediately after the flood season of 1865-66; for if sites are available, the operations can be supervised more readily than in the Damooda, and the works maintained at a less cost, as labor is more abundant in this line of country; and this is urged, as the difficulties and expense that would attend the formation and maintenance of the reservoirs on the Damooda would, from the nature of the localities, be very expensive, and if sites are found on the tributaries of the Burrakur, the immediate results would be more beneficial.

No. CLXIII.

NOTES ON THE SLIDE RULE.

By Captain W. H. Mackesy, *Executive Engineer.*

The Slide Rule is so little known to the Officers and Subordinates of the Public Works Department, that a few remarks showing the manner in which it can be used to facilitate calculations, and solve at sight many problems of constant occurrence in estimates, &c., may prove useful. It would be difficult to exaggerate the great saving of time, in working out detailed measurements, striking rates, calculating strains, determining the strength of beams, &c., &c., which results from its use. It must, at the same time, be clearly understood that its answers are only approximate; though the error never exceeds $\frac{1}{500}$th, and will in most cases be less than this.

The Slide Rule is usually constructed of box-wood; is 12 inches long, and has a groove $\frac{3}{8}$-inch broad on its face, in which a slip of brass or box-wood slides freely, the face of the slide being flush with the face of the rule. Above and below the slide, there are two scales, marked A and D, and on the slide itself two scales, B and C. A, B and C are precisely alike, but the divisions on D are twice as large as those on A, B and C. D is termed a line of single radius; A, B and C, lines of double radii.

These scales are logarithmic scales; that is to say, the space from 1 on the left of one of the scales to any division, is proportional to the logarithm of that division—thus, if the distance from 1 to 1 (or 10) be taken = unity

The distance from 1 to 2 = ·301 or log of 2
„ „ 1 to 3 = ·477 „ 3
„ „ 1 to 7·4 = ·869 „ 7·4

and so on. Since, therefore, multiplication or division by logarithms is performed by adding or subtracting the logarithm of the numbers, it is evident that the above described arrangement of the scales on the Slide Rule enables us to perform multiplication or division by simple inspection.

Thus, place 1 on the slide against 2 on the rule, and against 3 on the slide, will be seen 6 on the rule; or the product of 2 and 3. We have, in fact, added the space representing the log of 3 to the space representing the log of 2, and have thus obtained a space $= \cdot 301 + \cdot 477 = \cdot 778 =$ log of 6; and according to the principles upon which the scale is graduated, this space is marked 6.

Similarly, any two numbers whatever can be multiplied together. Division is performed by reversing this process; the divisor is subtracted from the dividend by placing the divisor on the slide against the dividend on the stock; and against 1 on the slide is found the quotient. Thus place 3 on B against 6 on A; and against 1 on B will be found the quotient 2 on A.

Any two numbers can be multiplied together and divided by a third, by combining these operations—thus, $\frac{2 \times 3}{4} = x = \left(\frac{2}{4}\right) \times 3$; or, by logs. Log $x =$ log 3 $-$ (log 4 $-$ log 2). This is effected on the Slide Rule, by subtracting the difference between the spaces representing the logs of 4 and 2 from the space representing the log of 3. Thus, place 4 on B against 3 on A; and against 2 on B will be found 1·5 on A, $= x$.

It is the same thing to put 4 on B against 2 on A; for against 3 on B will be found 1·5 on A. This is evident, for $\frac{2 \times 3}{4} = x$, may be written either $\frac{2}{4} \times 3 = x$, or $\frac{3}{4} \times 2 = x$.

The spaces on D being double the spaces on A, B and C, are equal to the logarithm of the squares of the numbers on A, B and C; and if C be shut in even with D, the number on C will be found to be the squares of the numbers below them on D.

The proportions on the slide rule are as follows:—Set the slide at random—

A	*a*	*c*	*e*
B	*b*	*d*	*f*
C		*g*	*k*
D		*h*	*l*

ab, *cd*, *ef*, *gh*, *kl*, being any pairs of numbers standing against each other on the instrument—

$$\text{Then } \frac{a}{b} = \frac{c}{d} = \frac{e}{f} = \frac{h^2}{g} = \frac{l^2}{k}; \text{ also } \frac{h}{\sqrt{g}} = \frac{l}{\sqrt{k}}$$

For example, set 2 on B against 3 on A—

$$\text{Then } \frac{3}{2} = \frac{4 \cdot 5}{3} = \frac{7 \cdot 5}{5} = \frac{3^2}{6} = \frac{6^2}{24}$$

Also, 16 set on C against 2 on D, then $\frac{\sqrt{16}}{2} = \frac{\sqrt{36}}{3} = \frac{\sqrt{64}}{4} = \frac{\sqrt{81}}{4 \cdot 5}$

If the slide be taken out and inverted—

A	a	c	e
Ɔ	b	d	f
ᗺ	g	k	
D	h	l	

ab, cd, ef, gh, kl, being any pairs of numbers standing against each other on the instrument.

$$\text{Then } a \times b = c \times d = e \times f = g \times h^2 = k \times l^2.$$

$$\text{Also } \sqrt{g} \times h = \sqrt{k} \times l.$$

For example, invert the slide and set 2 on C against 6 on A.

$$\text{Then } 8 \times 1 \cdot 5 = 6 \times 2 = 4 \times 3 = 12 \times 1 = 4^2 \times \cdot 75 = 2^2 \times 3.$$

Also set 81 on C against 1 on D, then $\sqrt{81} \times 1 = \sqrt{64} \times 1 \cdot 125 = \sqrt{16} \times 2 \cdot 25$.

When a question is in the form $x = \frac{a\,d}{b}$, or $b : a :: d : x$, all the terms being constant, or either a or d varying, the slide is not inverted; if, however, b varies, the slide should be inverted. a and d are placed in contact, and against the variable number b will be found the variable answer x.

An example of each case follows.

I. If 3,575 cubic feet of earthwork cost Rs. 15, what is the rate per 1,000 cubic feet?

A	4·2 = 4-3-2	15 rupees
B	1000 c. ft.	3575 c. ft.

$4 \cdot 2 = \frac{15 \times 1000}{3575}$; or $3575 : 1000 :: 15 : 4 \cdot 2$.

In this case all terms of the proportion are constant.

II. If the area of a circle, 12 inches diameter is ·7854 superficial feet; find the area of a circle n inches diameter?

C	·7854	1·23	1 77	4 91
D	12 in.	15 in.	18 in.	30 in.

Area, sq. ft. $= \frac{n^2 \times \cdot 7854}{12^2}$

$$12^2 : n^2 :: \cdot 7854 : \text{area square feet.}$$

$$\text{or } 12^2 : \cdot 7854 :: n^2 : \quad ,,$$

In this case one of the middle terms is variable, and is used to point out the answer.

III. If a railway train goes a quarter of a mile in n seconds; what is its rate in miles per hour?

A 3600 sec.	60 m.	45 m.	36 m.	30 m.
D ·25 mile	15 sec.	20 sec.	25 sec.	30

$$n'' : 3600'' : : \cdot 25 : \text{rate in miles per hour.}$$

$$\text{Rate in miles per hour} = \frac{3600'' \times \cdot 25}{n''}$$

In this case the divisor, or the first term of the proportion varies, and by inversion of the slide is used to point out the answer.

Some little difficulty is sometimes found by beginners in reading the slide, particularly between 1 and 2. Taking line A, and commencing from 1 on the left (which may be called ·01, ·1, 1, 10, 100, and so on), the readings are as follows:—Calling 1 on the left unity, we read—1·00, 1·02, 1·04, 1·06, 1·08, 1·10; then (missing the short division) 1·2, 1·3, 1·4, 1·5, 1·6, 1·7, 1·8, 1·9, 2·0, then (reading only the numbered divisions) 3·0, 4·0, 5·0, 6·0, 7·0, 8·0, 9 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100.

And on D, calling 1 on the left unity, we have 1·01, 1·02, 1·03, 1·04, 1·05, 1·06, 1·07, 1·08, 1·09, 1·1, then 1·2, 1·3, 1·4, 1·5, 1·6, 1·7, 1·8, 1·9, 2, 3, 4, 5, 6, 7, 8, 9, 10.

Should any difficulty be found in learning to read the rule, it is best overcome by setting the slide at random, and reading the numbers against each other; it will be at once seen whether the readings are correct or not as they should form equal fractions. Thus, set 2 against 21; against 1 will be found 10·5; against 12, 126—then $\frac{10 \cdot 5}{1} = \frac{21}{2} = \frac{126}{12}$, and so on, showing that the readings are correct.

The following formulæ will be found useful in the current work of the Department.

I. To find the contents of a log of timber by the customary rule (content = length × mean quarter girth squared). Take the length of the log in feet, and its mean girth in inches; the content is found as follows:—

C length in feet.	content in cub. feet (answer)
D 48	girth in inches
G. P.	

Example.—A log measures 27′ 6″ long, and 59″ mean girth; what number of cubic feet does it contain?

C 27·5	41·6 cubic feet
D 48	59
G. P.	

Answer, 41·6 cubic feet.

II. To find the contents of timber scantlings, length being given in feet, and breadth and depth in inches. $b \times d$ must be found either mentally or by the slide rule.

A	$b \times d$	content cubic feet
B	144 Divisor	length in feet

Example.—A beam measures 17′ 9″ × $5\frac{1}{2}$″ × 9″; what is its content?

$$5\tfrac{1}{2}'' \times 9'' = 49{\cdot}5$$

A	49·5	5·75
B	144 Divisor	17 75.

Answer, 5·75 cubic feet.

Should the beam be square, the rule is as follows :—

A	content cubic feet
B	length in feet
C	144
D	b

or

C	length in feet	Content cubic feet
D	12 G. P.	b

Example.—A beam measures 15′ × 5″ × 5″; what is its content?

A	2·6 cubic feet
B	15
C	144 = Divisor
D	5

Answer, 2·6 cubic feet.

III. To find the weight in maunds of rectangular bar-iron. Multiply the width by the thickness (both in eighths of inches), then—

A		$b \times d$ (eighths of an inch)
B		maunds.
C	length in feet.	maunds.
D	1253 G. P.	square side or mean square in eighths of an inch.

Example.—What is the weight of a quantity of bar-iron $2\frac{1}{4}$″ × $\frac{3}{8}$″, aggregating 79 running feet long?

$$\text{Section} = 18 \times 3 = 54.$$

A		54
B		2·73 maunds
C	79 feet	
D	1253 = G. P.	

Answer, 2·73 mds., or 2 md. 29 srs. 4 chs.

The seers and chittacks are found as follows :—

A	·73	29·25 seers
B	1	40

and again,

A	·25	4 chittacks
B	1	16

Example.—What does 107 running feet of $\frac{3}{4}$-inch square bar-iron weigh?

$\frac{3}{4}$-inch = $\frac{6}{8}$-inch.

$$\left\{\begin{array}{lll} C & 107 & 2{\cdot}45 \text{ maunds} \\ \hline D & 1253 & 6 \\ & \text{G. P.} & \end{array}\right. \quad \text{Answer, } 2{\cdot}45 \text{ maunds.}$$

IV. In round bar-iron the constant or G. P. (gauge point) is 1415.

Example.—What does 305 cubic feet of $\frac{1}{2}$-inch rod-iron weigh?

$\frac{1}{2}$-inch = $\frac{4}{8}$-inch.

$$\left\{\begin{array}{lll} C & 305 & 2{\cdot}45 \text{ maunds} \\ \hline D & 1415 & 4 \\ & \text{G. P.} & \end{array}\right. \quad \text{Answer, } 2{\cdot}45 \text{ maunds.}$$

Note.—The above constants are calculated on the supposition that a cubic inch of bar-iron weighs ·2754 lbs., and that there are 82·286 pounds in a maund.

For other metals, multiply the constants by—

$$\sqrt{\frac{481}{\text{Weight in lbs. of 1 cubic foot of the metal}}}\,; \text{ or } \sqrt{\frac{\text{Sp. grav. of iron}}{\text{Sp. grav. of metal}}}$$

This can be done by the slide.

V.

$$\left\{\begin{array}{lll} C & 481 & \text{weight of cubic foot (in pounds) of metal} \\ \hline D & \text{constant for metal.} & \text{constant or G. P. for iron.} \end{array}\right. ; \text{ or } \left\{\begin{array}{lll} C & 7{\cdot}7 = \text{spec. grav. of iron.} & \text{spec. grav. of metal.} \\ \hline D & \text{G. P. for metal.} & \text{G. P. for iron} \end{array}\right.$$

Example.—Weight of 1 cubic foot of bar copper is about 560 lbs.; find a new G. P. for rectangular bar copper.

$$\left\{\begin{array}{lll} C & 481 & 560 \\ \hline D & 1164 & 1253 \\ & \text{G. P.} & \end{array}\right. ; \text{ or } \left\{\begin{array}{lll} C & 7{\cdot}7 & 8{\cdot}96 \\ \hline D & 1162 & 1253 \\ & \text{G. P.} & \end{array}\right.$$

Example.—What is the weight of a bar of copper 25 feet long, and 1 inch square.

$$\left\{\begin{array}{lll} C & 25 & 1{\cdot}182 \text{ maunds} \\ \hline D & 1164 & 8 \\ & \text{G. P.} & \end{array}\right. . \quad \text{Answer, } 1{\cdot}182 \text{ maunds.}$$

In this example it will be observed that on setting 25 against 1164, the slide is outside 8, so that no answer is obtainable; it is, therefore, necessary to shift the slide one radius; this is done by shifting the slide until the same number is over 10 on the *right* of D, that was over 1 on the *left* of D before making the shift. In the present case the number over 1 is 1846 on

the first radius; shift the slide until 1846 on the second radius is over 10, the answer can then be read over 8, *i. e.*, 1·182.

VI. Given the cost of any metal in shillings per cwt.; find cost in rupees per maund.

A	·3673 multiplier	rupees per maund
B	1	shillings per cwt., or pounds per ton.

Example.—The last London price current for the following metals quotes following rates per ton. Give the equivalent rates per maund in rupees.

				R.	A.	P.
Copper, sheet,	£91,	=	rupees per maund,	33	8	0
Staffordshire bar-iron,	£8 15*s*.,	=	"	3	3	6
Swedish ditto,	£11 15*s*.,	=	"	4	4	6
White Lead,	£32,	=	"	11	12	4

VII. Given the uniform load on a beam of timber; to determine its scantling, so that it shall not deflect more than $\frac{1}{40}$-inch per foot of span.

From the formula $E = \frac{5}{8}\frac{l^3 W}{bd^3 \delta}$, putting $d = rh$ we obtain the formulæ—

$$b = B \sqrt[4]{W l^2}, \text{ and } d = D \sqrt[4]{W l^2}.$$

$$\text{where } B = \sqrt[4]{\frac{1}{r^3} \times \frac{25}{E}}, \text{ and } D = \sqrt[4]{r \times \frac{25}{E}}.$$

Some of the values of B and D for sál are given in following table, taking value of E for sál at 4209.

Wood.	E.	$\sqrt[4]{\frac{25}{E}}$	Values of r.				
			1 . 1	$\sqrt{2}:1$	3 : 2	5 : 3	2 : 1
Values of $\sqrt[4]{\frac{1}{r^3}}$.			1	·7712	·7378	·6817	·5946
Values of $\sqrt[4]{r}$.			1	1·092	1·107	1·136	1·1992
Sál, ... B	4209	·2776	·278	·214	·205	·189	·165
" ... ... D			·278	·303	·307	·315	·330

An example will be given after VIII. Value of E was taken from Conductor Skinner's table, in the "Roorkee Treatise of Civil Engineering." If Rankine's formula be used, his value of E for sál, 2,420,000, will be

found to give nearly the same results, the constant 2776 becoming ·2585. Rankine's formula for the deflection of a beam under an equally distributed load is $\delta = \frac{5}{4\,E} \times \frac{W\left(\frac{l}{2}\right)^3}{bd^3}$, all the dimensions being in inches.

VIII. To determine the scantling of a beam of timber to break with any fixed multiple of the uniformly distributed load.

If f be the co-efficient of safety, $W = \frac{bd^2}{l} \times \frac{2\,c}{f}$; and if $d = rb$, $b = B \sqrt[3]{Wl}$, and $d = D \sqrt{Wl}$, when $B = \sqrt[3]{\frac{f}{2c}} \times \sqrt[3]{\frac{1}{r^2}}$, and $D = \sqrt[3]{\frac{f}{2c}} \times \sqrt[3]{r}$.

Some of the values of B and D for sál are given in the following table :—

Wood.	f	c	$\sqrt[3]{\frac{f}{2c}}$	Values of r.				
				1 : 1	$\sqrt{2}$: 1	3 : 2	5 : 3	2 : 1
Values of, ...			$\sqrt[3]{\frac{1}{r^2}}$	1	·7937	·7632	·7114	·6299
			$\sqrt[3]{r}$	1	1·122	1·145	1·186	1·2598
Sál, ... B	10	880	·1785	·179	·142	·136	·127	·112
" ... ... D	"	"	"	·179	·200	·204	·213	·225
" ... ... B	5	"	·1416	·142	·112	·108	·1005	·089
" ... ... D	"	"	"	·142	·159	·162	·168	·177

Example.—A beam for a flat roof, span 19′ 6″, has to carry a uniformly distributed load of 4,500 pounds. What scantling should be given to it—1st, That it may not deflect more than $\frac{1}{480}$ of its length under the load; 2nd, That it may just break under 10 times its permanent load; and 3rd, That it may just break under 5 times its permanent load ?

1*st.* b or d = (B or D) × $\sqrt[4]{WL^2}$

a { A 1,710,000 = WL²
B 4,500 = W
C 1
D 19·5 = l }

b { C 1 1,710,000 = Wl^2 1,309 = $\sqrt{Wl^2}$
D 1 1,309 = $\sqrt{Wl^2}$ 36·28 = $\sqrt[4]{Wl^2}$ }

$\sqrt[4]{Wl^2}$ is obtained by simple inspection, as shown in *b*.

c	A	36·28	10·02	7·78	11	7·43	11·2	scantlings
	B	1	278	·214	·303	·205	·307	multipliers
			1 . 1	$\sqrt{2}$: 1		3 : 2		

The scantlings of equal stiffness are given by inspection 10″·02 × 10″·02, or 7″·78 × 11″, or 7″·43 × 11″·2, or 6″·85 × 11″·44, or 6″ × 12″.

2nd. b or $d = (B \times D) \times \sqrt[3]{WL}$

a	A	4,500 = W	87,750 = WL
	B	1	19·5 = L

b	A		87 750 = WL	
	B		44·4	
	C	1	·032 = $\overline{·179}^2$	squares of multipliers
	D	44·4 $\sqrt[3]{WL}$	7 95 inches	scantlings

The first figure of the cube root of 87,750 is evidently 4, set 1 a little beyond 4 on D, and by successive trials, move the slide until the same number is under 1 or D; that is, under the cube whose root is required on A, this number will be the required cube root; *e. g.*, setting 1 on 43, it is seen that 47·5 is under 8775. Shifting 1 to 44, under 8775 is found 45·4, and at last, shifting 1 to 44·4, the same number is found under 8775; 44·4 is therefore the approximate root. If now the squares of the constants be taken on C, the scantlings will be found on D; or otherwise, set as in *d*, and the scantlings will be found by simple inspection.

d	A	44·4 = $\sqrt[3]{WL}$	7·95	6·31 ×	8·9	6·04 ×	9·05	
	B	1	·179	·142	·200	·136	·204	
				$\sqrt{2}$: 1		3 : 2		

5·64 ×	9·45	4·97 ×	10	scantlings
·127	213	·112	·225	multipliers
5 : 3		2 : 1		

3rd. That the beam may just break under 5 times the permanent load. $\sqrt[3]{WL}$ is found, as before, and the setting is

A	44·4	6·3	4·98 ×	7·05	4·8 ×	7·2
B	1	·142	·112	·159	·108	·162
			$\sqrt{2}$: 1		3 : 2	

4·49 ×	7·45	3·96 ×	7·84	scantlings
·1005	·168	·089	·177	multipliers
5 : 3		2 : 1		

Comparing the results the scantlings are as follows:—

	Inches.	Inches.	Inches.	Inches.	Inches.
For stiffness, ...	10×10	$7\frac{3}{4} \times 11$	$7\frac{1}{2} \times 11\frac{1}{4}$	$6\frac{7}{8} \times 11\frac{1}{2}$	6×12
Factor of safety, 10, for strength,	8×8	$6\frac{3}{8} \times 9$	6×9	$5\frac{5}{8} \times 9\frac{1}{2}$	5×10
Factor of safety, 5, ...	$6\frac{3}{8} \times 6\frac{3}{8}$	5×7	$4\frac{7}{8} \times 7\frac{1}{4}$	$4\frac{1}{2} \times 7\frac{1}{2}$	$4 \times 7\frac{7}{8}$

E and c being known, multipliers may be calculated for any wood or any proportion of breadth to depth.

IX. To multiply three numbers together, set the reciprocal of one of the numbers on C against one of the remaining numbers on A, and against the third number on C, will be found the product.

Example.—What is the content of a wall, measuring $274' \times 2'\ 6'' \times 5'\ 3''$?

The reciprocal of $2'\ 6''$, or 2·5 is ·4.

$$\begin{cases} \text{A} \quad 274 \quad 3{,}600 \\ \text{B} \quad \cdot 4 \quad 5{\cdot}25 \end{cases}$$

The slide gives the answer 3,600. The correct product (omitting fraction) is 3,596—error is $\frac{4}{3{,}596} = \frac{1}{899}$, say $\frac{1}{900}$.

This rule will often be found very useful in checking calculations.

X. On most slide rules, tables of *Gauge Points* and *Divisors*, will be found engraved. Their use and explanation is as follows:—In the formulæ, $x = \frac{a \times \text{B}}{\text{C}}$; $x = \frac{a \times b}{\text{C}}$; $x = \frac{a \times b}{\sqrt{\text{C}^2}}$; B and C being constants, B is termed a multiplier, C a *Divisor*, and $\sqrt{\text{C}}$ a *Gauge Point*, being the square root of the divisor, and used only on D.

In page 355, ·3673 is a multiplier.

In page 353, 144 is a divisor. Taking the second example, find the content of a beam 15′ long $\times$ 5″ $\times$ 5″, the rule might have been set

$$\begin{cases} \text{C} \quad 15 \text{ ft. long} \quad 2{\cdot}6 \text{ cubic feet} \\ \text{D} \quad 12 = (\sqrt{144}) \quad 5 \text{ inches} \end{cases}$$

In this case 12 is a Gauge Point, being the only root of the divisor 144.

The divisors are usually engraved in a tabular form, as under—F, F, F, means all dimensions in feet; F, I, I, means two dimensions in inches; and I, I, I, means all dimensions in inches.

Divisors.	Parallelopipeds.			Cylinders.		Spheres.	
	F, F, F.	F, I, I.	I, I, I.	F, I.	I, I.	F.	I.
Cubic feet, ...	100	144	1728	183	220	191	330
Gallons, ...	160	231	277	294	353	306	530
lbs. Wrought-iron, ...	205	296	355	377	452	392	678
lbs. Wrought-copper, ..	180	259	311	330	396	344	594

Example.—Find the weight of a sphere of copper, $6\frac{1}{2}$ inches in diameter.

A	594 divisor	
B	6·5	
C		46 lbs.
D		6·5

Here $x = \frac{(6 \cdot 5)^2 \times 6 \cdot 5}{594}$.

Example.—Find the weight of a wrought-iron pillar, 11 feet long, $4\frac{1}{4}$ inches diameter.

A	377 divisor	
B	11 feet	
C		523 lbs.
D		$4\frac{1}{4}$ in. diameter

Here $x = \frac{11 \times \overline{4 \cdot 25}^2}{377}$

How many gallons are there in a cistern, 7 feet long, 66 broad, and 31 inches deep.

By slide rule $66 \times 31 = 2046$, or $\sqrt{66 \times 31} = 45 \cdot 3$.

This last mean square is found thus—

C	31	66
D	31	45·3 = mean square

A	231 divisor	2046 = 66 × 31
B	7 feet	622 gallons.
C		622 gallons.
D		45·3 (mean square)

The foregoing examples and explanation will establish the utility of the slide rule. Those wishing to make themselves master of the instrument, should procure "Bayley's Hand-Book of the Slide Rule," price 6*s*., published by "Bell and Daldy," Fleet-Street. This work contains an immense number of useful formulæ, and a complete explanation of the instrument.

The best Slide Rule is made by Elliott, 449, Strand. He charges 14*s*. for the two slide rule, and 7*s*. for the single slide. The second slide

of the two slide rule contains lines of sines and tangents; and all cases of right-angled and oblique plane triangles can be solved approximately by it at sight. The back of the slide has a line of sines to radius D on it (this is really useless, as it only serves the purpose of a table of natural sines. The short printed table in Molesworth (and other) Pocket-Books, is in every way superior to it), and an extra line of tangents above 45°: this line is also of very little use. It would be better to suppress these lines and substitute a line of 5th powers to be used with D. This line would be found useful in solving hydraulic problems.

On the back of the slide AB, there is a line marked *Num.*, which, shut in even with D, gives the logs of the number under it; it is quite useless, as logs can only be taken out to the third figure, that is only approximately. The short 4 figure table in Molesworth is far more useful in every way. There is also a line E, which, when shut in even with D, gives the cube of the number under it. This line also is of little use, as all questions regarding which can be solved by the lines D and C. It would be far better to omit these lines and substitute a double line D to unite with A and D; with such a line the first example in VIII. would be solved as follows, in two settings of the rule:—

a			
	A	$4500 = W$	$1{,}710{,}000 = WL^2$
	D	1	$19\ 5 = L$
	D		

b						
	A	$WL^2 = 1{,}710{,}000$				
	D	1	19·5	278	214	303 multipliers
	D	$19{\cdot}5 = \sqrt[4]{WL^2}$		10·02	$7{\cdot}78 \times 11$	scantlings

Only the following cases can be solved with the lines ABCD; $x = \frac{a^2 b}{c^2}$ or $x = \frac{a \times b}{\sqrt{c}}$; it is evident, that *all* possible cases of square and square roots could be solved by the proposed lines ADD. Common Engineer's slide rules of box, with brass slides, can be obtained from Thompson & Co., Calcutta, for Rs. 3 or 4, the divisions are stamped and not cut. A superior kind can be got from Newman or Lepage for about Rs. 10. They are both in every way inferior to the regular box-wood slide rule with box-wood slide made by Elliott, as the brass slide invariably sticks in the hot weather, and is very liable to injury. A very superior instrument, called the "Engineer's Circular Slide Rule," can be obtained from Newman for about Rs. 20. It is a brass disk about 3½ inches diameter, with a white

metal slide inlaid on its face. It is very correctly divided, and is very portable and convenient; the only objection to it is, that the slide cannot be inverted. No other pattern of slide rules are procurable in Calcutta.

The article, by Professor De Morgan, on the "Slide Rule" in the "English Cyclopædia," division Arts and Sciences, contains a great deal of information on the subject, and is well worth referring to. A quotation from this article will appropriately conclude these remarks.

"This instrument (*the slide rule*) has been greatly undervalued in our country, in which it was invented, and is very little known on the Continent; for though a French work on the subject, published in 1825, which is followed by the writer of a more recent mathematical dictionary in the same language, assures us that in England the sliding rule is taught at schools, at the same time with the letters of the alphabet; we believe it would be more correct to say, that nine Englishmen out of ten would not know what the instrument was for if they saw it, and that of those who even knew what it is for, not one in a hundred would be able to work a simple question by means of it. For a few shillings most persons might put into their pockets some hundred times as much power of calculation as they have in their heads, and the use of the instrument is attainable without any knowledge of the properties of logarithms, on which its principle depends."

9th August, 1867. W. H. M.

No. CLXIV.

MILROY'S EXCAVATING APPARATUS.

(From "Engineering" of March 29th, 1867.)

The following description of an apparatus for sinking foundations in Sand is given as likely to be well adapted for many cases of Indian rivers :—

A railway bridge of some magnitude is now in course of erection at Glasgow for carrying the City of Glasgow Union Railways over the river Clyde. The bridge, which is on the wrought-iron lattice girder principle, will consist of five water spans, each 75 feet in the clear, and two land spans of .65 feet each. The girders will be 8 feet deep and the bridge will be laid with a double line of way. The girders will rest upon granite columns, and the abutments will be of masonry. The superstructure will be carried on cast-iron cylinders 8 feet 4 inches in diameter, some of which have already been sunk to a depth of 85 feet through the sand down to the solid rock which forms the bed of the river. When down to the necessary depth the cylinders are filled in with concrete to about the ground level; the water is then pumped out and brick-work is built up to high-water level, at which point the granite columns commence.

The process of sinking the cylinders has been shortened and the operation greatly facilitated by the adoption of an excavating apparatus, the invention of Mr. John Milroy. This apparatus is shown in [*Plate* LIV.], in which *Fig.* 1 represents a side elevation, partly in vertical section, of the principal part of the machine, which is termed the excavator; *Fig.* 2 being a plan view. A series of spades or digging and lifting blades, *a*, are hinged to an octagonal iron framework, *b*, into which they exactly fit when

closed. The spades are hinged to the outer side or rim of the frame, and are formed with sides projecting inwards, which enable them to take better hold of the earth. When the apparatus is being lowered over the spot to be excavated the spades are open and hang in the position shown in *Fig.* 1. With the spades hanging thus the apparatus is lowered as far as it will go, and the spades having entered the soil are drawn inwards through the ground each into its own opening in the frame, bringing the earth with it. The frame and spades thus brought together form a close vessel, and in this condition the apparatus is drawn to surface, full of the soil. To prevent leakage and to make good joints, strips of India-rubber are attached to the underside of the inner octagonal portion of the framework and the T-iron arms connecting the inner and outer framing. Against this India-rubber, the edges of the spades press, and, when working in soft soils, leakage is thus prevented.

We now come to the working of this apparatus as carried out on the Clyde Bridge works, to illustrate which we have shown, at *Fig.* 3 in the *Plate*, a side elevation of one of the cylinders now being sunk, and the necessary timber structure, and at *Fig.* 4, a vertical section through the centre of *Fig.* 3. The cylinders *a*, *a*, are 8 feet 4 inches in diameter, cast in 6 feet lengths, and are kept in position by four guide piles *b*, *b*. The outer piles are for carrying the platform, gantry, &c., in the usual manner. The main chain *c*, is worked by an engine placed as indicated in *Fig.* 4, which is employed to raise or lower the apparatus. The excavator is attached to this main chain by two sets of chains A and B, *Fig.* 1. The chains of set A, all of equal length, are each fixed to the outer frame of the excavator, and after uniting upon a ring are joined to the main chain a short distance above its junction with the other set of chains B, by a length of single chain *d*. When the apparatus is descending, this length of chain is looped up by the monkey hook. There are eight chains to set B, all of equal length, and attached at their upper ends to the main chain in the way we have shown. These last chains are for the purpose of pulling in the spades up to the frame with the soil which they drag with them, and for raising the apparatus bodily to the staging above. When lowering the excavator, the connecting chain *d*, of the outer set of chains A, is looped up by means of the monkey hook, the chains of set B, being thereby rendered quite slack—until the excavator reaches the bottom. The monkey hook is then thrown out of gear by means of the rope shown at *e*,

which slackens the outer set of chains, and, upon the hoisting being commenced, the inner set of chains is brought into tension, the spades drawn in and the whole machine raised to surface.

In order to ensure the excavator being both kept and forced down at the moment when the spades are being drawn into their places in the frame, a very effective arrangement, shown in *Fig.* 4, is adopted. Two holding-down chains are fixed to opposite sides of the spade frame, and which pass under pulleys held down near the bottom of the excavation, and thence up to winding axles placed on the staging above. These winding axles are formed with enlarged drums, and also with handles for turning them by; and the holding-down chains are hauled up quickly by drawing ropes off the drums, on which they are re-wound by the operation of drawing up the excavator. The bottom pulleys for the holding-down chains are carried by timber spars or leaders, placed vertically, and which are held inside the cylinders. They are kept apart at their lower ends by a stout iron hoop, to the opposite sides of which the leaders are fixed, whilst their upper ends are made fast to the cylinder itself. As the excavation proceeds these leaders move downwards with the cylinders, being lengthened from above. The holding-down chains are hauled tight as the excavator descends, and when it has reached the ground surface, sufficient strain is put on them to force the spades into the earth, to keep the frame from rising whilst they are being drawn inwards, and to ensure their taking hold of the ground. As soon as the workmen feel that the spades are drawn close in, the holding-down chains are released and the excavator is raised up to be emptied. This is effected by running a lorry under the excavator and on which it rests; the outer set of chains A, are then hooked up, and the excavator being raised a little, the spades fall open and the soil is discharged into the lorry. Mr. Milroy's apparatus has been found to effect considerable economy in the Clyde Bridge works from the simple and expeditious manner in which it performs its duties. Mr. J. F. Blair, the engineer of the works, has expressed to us his high appreciation of this excavator, and his thorough satisfaction with the results of its working.

No. CLXV.

GANGES CANAL WORK RATES.

By T. Login, *Esquire, C.E., late Superintendent, Northern Division, Ganges Canal.*

These rates were prepared at the request of Sir P. T. Cautley, while the works were in progress, but were kept back at the time as the Director was desirous to have the rates of Block sinking at Dhunowrie added to them. Press of work prevented this being done, and it is only now, when examining some old records, that these rates have turned up.

As they are obtained from *actual* measurements of large quantities of work, they may be considered of some value in showing what work a man can perform where task-work is introduced. Every evening the *moonshee* had to measure the work done, and report any deficiency, and at the same time the *mistrie* gave out the tasks for the following day.

If it was thought necessary, the workmen on the following morning were made aware that the full quantity of work was not done; and at the end of the month, the necessary deductions were made from their pay, while those who did good work were at the same time rewarded; the deductions being generally over one per cent. on the whole work done and the rewards a little under it.

Boulder Masonry of Puttree Works.—In forming the standard of mason's wages, two rates have been taken, viz., Rs. 8 per month and Rs. 4; the former for masons and the latter for beldar masons. The former had not only to work themselves, but also to superintend the work done by the beldar masons, a certain number being told off to each mason.

At first there were nearly as many masons as beldars; but the latter being picked men, soon became expert workmen, so that latterly only a few masons were employed in keeping the work in line and horizontal.

As these mason beldars improved, their wages increased in due proportion, but in the rates, I have classed all masons by *trade* under the higher rate of pay, and the beldar masons under the lower.*

The advantage of having beldar masons was, that whenever a sufficient supply of boulders could not be had, they were employed in digging; and, also, we were in a manner independent of masons.

Average Cost of Men and Materials required for 100 *cubic feet of* BOULDER MASONRY.

Workmen.	Average number.	Amount of wages per mensem.			Cost.			Remarks.
		RS	A.	P.	RS.	A.	P.	
Masons, ..	0·092	8	0	0	0	0	4·633	30½ days in the month.
Beldar masons, ..	1 365	4	0	0	0	2	10·371	
Beldars, ..	0 221	6	0	0	0	0	8 347	
Ditto, ..	6 631	4	0	0	0	13	10 971	
Total cost Labor, ..					1	1	10 322	

Description of materials.	Number or quantity.	Rate.	Cost.			Remarks.
		RS. A. P.	RS.	A.	P.	
Boulders, maunds, ...	102 984	4 0 0 per 100 mds.	4	1	10·917	100 cubic feet of boulders, when not less than one cubic foot each stone, equal 112 maunds, bazar weight, of 90 Rs to the seer. If less than 1 foot, 110 maunds.
Broken bricks, cub. ft.,	27·870	900 0 0 per lakh.	0	0	4·159	
Lime, „	15·591	17 0 0 per 100 c. f.	2	10	4·890	
Soorkee, „	14 279	11 8 0 per 100 c. f.	0	10	3·280	
Sand, „	17·000	1 4 0 per 100 c f.	0	3	4 800	
Lime sifting, „	2 229	6 0 0 per 100 c. f.	0	2	1·678	
Soorkee, „	3·541	8 0 0 per 100 c. f.	0	4	6·390	
Oil, chittacks,	0·0·277	5 0 0	0	0	0·415	
Twine, seers,	0·0·003	1 0 0	0	0	0·360	
Total cost Materials, ...			9	1·	0·889	
Total cost for 100 cubic feet, ...			10	2	11 211	

This rate is procured from 3,09,104 cubic feet of boulder masonry in the flooring and foundations of the Puttrie Superpassage, consisting of a large flat surface of about 80,000 square feet, the greatest thickness not exceed-

* In 1863, one of these beldar masons was still employed, and received Rs. 9 a month, he having become an expert mason.

ing 4½ feet; all the work was executed from 16 to 21 feet below the natural spring level. The use of bheesties was not requisite, the greatest difficulty being to keep the foundations sufficiently dry during the progress of the work.

The rate of boulders is the price they cost, and not the office rate; so it shows what boulders can be carted for, at an average distance of six miles; and all the sand is charged at the rate it was carted, a distance of 1¼ miles, to the works; though a limited quantity was found 1,000 feet from the work, the cost of removing which is included in the labor. Particular care was also taken in having the sand *well washed*—which has also been charged on labor—those who were employed on this duty having also to mix the mortar. The broken bricks were used to fill up the spaces between the boulders, thereby getting rid of the broken bricks that were too hard for being pounded into soorkee, and saving a considerable quantity of mortar.

The rate of labor in a great measure depended on the distance the materials had to be carried. One month the average distance being 400 feet, the labor was Rs. 1-7-6 per 100 cubic feet; and another occasion the carters were able to bring the boulders to within 50 feet of where they were required, and the rate was only Rs. 0-12-7 per 100 cubic feet.

The mean distance for the whole work was 175 feet.

To prevent mistakes in the progress, the whole work done was measured up monthly, and the progress given in former months deducted from this total; thus, on the completion of the work to some certain height, the quantities done each month were added together, and had to agree with the total progress.

Rates obtained from the Masonry of the superstructure of a portion of the Puttrie works during November and December 1852, *and January, February, March, April and May* 1853.

LABOR.

Description.	Average number.	Wages per month.			Cost.			Remarks.
		RS.	A.	P.	RS.	A.	P.	
Masons, ...	3·442	8	0	0	0	14	5·3	30½ days in the month.
Bheesties, ...	0·325	4	8	0	0	0	9·8	
Beldars, ...	0 161	6	0	0	0	0	6·1	
Ditto, ...	4 838	4	0	0	0	10	1·8	
Total cost Labor, ...					1	9	11·0	

MATERIALS.

Description of materials.	Average quantity.	Rate	Cost. RS.	A.	P.	Remarks.
Bricks, ..	875·00	Rs. 1000 per lakh.	8	12	0	Bricks measured 12" × 6" × 2¼".
Lime, cubic feet,	15·02	Rs. 18 per 100 c. f.	2	11	3·1	
Soorkee, ditto, ..	30 04	Rs. 11-8 per 100 c. f.	3	7	3·3	
Oil, chittacks, ..	00·41	Rs. 5.	0	0	0·6	
Twine, seers, ..	00 05	Rs. 1.	0	0	0 6	
Total cost Materials, ...			14	8	6·4	
Total cost per 100 cubic feet, ..			16	8	6·4	

The above rate is got from a progress of 1,40,615 cubic feet of masonry of the superstructure of the Puttrie Superpassage and abutments; the piers being walls each 310 feet long by 4½ thick, the arch springing 12 feet above the flooring. The abutments were 6 feet thick. Particular care had to be taken that the surfaces were smooth and straight, as they had to be plastered* with plaster not exceeding ¼ of an inch at the thickest part, so that the outside bricks had their faces dressed, and all the bricks of the skew backs had also to be dressed.

The materials had to be brought from an average distance of nearly 200 feet, as it was impossible to cart the bricks nearer, on account of the extent of the work, covering 80,000 square feet in area; so as to not overcrowd the works, there being boulder masonry, plastering, excavation and piling, all carried on at the same time. The proportion of bricks in 100 cubic feet masonry when set, is 80·33, and of mortar 19·67 per cent., and the thickness of joints from ¼ to ⅓ of an inch; also a large proportion of the bricks were half bricks.

Rate obtained from the Masonry of the Puttrie Superpassage superstructure, built of English sized bricks, 10" × 4½" × 3", *during December* 1852, *January and February* 1853.

LABOR.

Description.	Average number.	Rate per month. RS.	A.	P.	Cost. RS.	A.	P.	Remarks.
Masons.	3·121	8	0	0	0	13	1·1	
Bheesties, ...	0·171	4	8	0	0	0	4·9	
Beldars, ...	0·163	6	0	0	0	0	6·1	
Ditto, ...	4·000	4	0	0	0	8	4·7	
Total cost Labor, ...					1	6	4·8	

* *See* Plaster rate.

MATERIALS.

Description.	Average quantity.	Rate.	Cost.			Remarks.
			RS.	A.	P.	
Bricks, 10-inch, ...	1·200	Rs. 729-2-8 per lakh.	8	12	0	
Lime, cubic feet,	14·081	Rs 18-0-0 per 100 c. f.	2	8	6 6	
Soorkee, „ ..	28·161	Rs 11-8-0 per 100 c. f.	3	3	9 8	
Oil, chittacks, ...	00 1 30	Rs. 5.	0	0	1 9	
Twine, seers, ...	0·00·114	Rs. 40.	0	0	1·4	
Total cost Materials, ...			14	8	7 7	
Total cost for 100 cubic feet, ...			15	15	0·5	

The above rate is got from 12,272 cubic feet of superstructure masonry of Puttrie works, built of 10-inch bricks, under the same circumstances as the former. Workmen not employed on Sundays, but receiving pay for that day.

Average of men and materials required for 100 *cubic feet of* BRICK-ON-EDGE MASONRY *of the flooring of the Puttrie Superpassage of* 12″ × 6″ × 2½″ *bricks.*

LABOR.

Description.	Average number.	Rate per month.			Cost.			Remarks.
		RS.	A.	P.	RS.	A.	P.	
Mason, ...	8·083	8	0	0	2	1	11·0	30½ days in the month. Average wages of masons, Rupees 7-3-2 per month.
Bheestie, ...	0·448	4	8	0	0	1	0·8	
Beldar, ...	0·214	6	0	0	0	0	8·1	
Ditto, ...	6·355	4	0	0	0	13	4·0	
Bullocks, each, ...	0·636	0	6	0	0	3	9·7	
Total cost Labor, ...					3	4	9·6	

MATERIALS.

Description.	Average quantity.	Rate.	Cost.			Remarks.
			RS.	A.	P.	
Bricks 2½ inches,	875	Rs. 1000-0-0 lakh.	8	12	0	
Lime, cubic feet,	11·848	Rs. 18-0-0 per 100 c. f.	2	2	1·5	
Soorkee, „ ...	23·696	Rs. 11-8-0 per 100 c. f.	2	7	4·2	
Oil, chittacks, ...	0 0 8	Rs. 5.	0	0	1·2	
Twine, seers, ...	0·0·08	Rs. 1.	0	0	0·0	
Total cost Material, ..			13	6	2·3	
Total cost of 100 cubic feet, ..			16	10	11·9	

The above rate is got from a progress 23,885 cubic feet, or 57,770 superficial feet of flooring of the Puttrie Superpassage; all the bricks were selected, and none but those of the best quality used; hence the extra labor in supplying the masons and dressing the bricks.*

Rates obtained from the PLASTERING *of the Puttrie Superpassage during the months of January, February and March,* 1853.

Description.	Average number	Rate per month.	Cost.			Remarks.
		RS A P.				
Masons, ...	1·637	8 0 0	0	6	10·4	
Bheesties, ...	0 086	4 8 0	0	0	2·4	
Mates, ...	0 046	6 0 0	0	0	1 6	
Beldars, ...	1 378	4 0 0	0	2	10·6	
Total cost Labor, ...			0	10	1·0	

Description.	Average number.	Rate.	Cost.			Remarks.
		RS. A. P	RS.	A.	P.	
Lime, cubic feet, ...	1	17 0 0 per 100 c. f	0	2	8 64	
Soorkee, „ ...	2	11 8 0 per 100 c. f	0	3	8·16	
Oil, chittacks, ...	0·165	5 0 0	0	0	3 75	
Total cost Materials, ...			0	6	8 55	
Total cost for 100 superficial feet, ...			1	0	9 55	

The progress for the above three months was 1,45,806·5 square feet of plaster. The brick-work being face dressed, the mortar was simply rubbed on the brick-work by beldars and polished up by masons. This work is to be seen on the interior of the lock chamber and the sides of piers.

EXCAVATION *by rail of Dhunowrie works by servant Beldars.—First case.*—Labor, @ 1-4-5 per 1,000 c. ft. by rail; ditto, @ 2-1-1 per 1,000 c. ft. in baskets.

* Six of the bays of the superpassage had the bricks for this brick-on-edge work, from native kilns

The rail is on a slope of 1 foot per 400. Four beldars to one wagon, whose duty is to load the wagon, carrying the earth an average distance of 50 feet, and to propel the wagon a distance of 900 feet, unload, and bring it back. The earth contains a large proportion of sand, and is easily dug. Keeping the line clear and oiling the wagons, &c., not included in the above rates.

In the *Second case* the beldars have to remove the earth brought by rail a distance of 250 feet, and at a height of 15 feet.

Cost of Excavating 1,000 *cubic feet of Earth by contract.*

Depth.	First.	Second.
	R. A. P.	R. A. P.
Not exceeding 5 feet, ...	1 4 6	..
„ „ 7½ feet,..	..	1 4 6

Puttree Bunds.—Work done by contract. In the 1*st* case the earth was taken from the Puttrie bunds, and a little care had to be taken in forming the slopes; but it was not required that they should be carefully dressed. All the measurments varied according to the height of bund, except breadth at top, and from A to B.

Rutmoo Inlet.—The 2*nd* case was three parallel cuts, for the new course of the Rutmoo, of 50 feet each, leaving spaces of 60 feet breath for the earth to be thrown on.

The excavation in both cases in ordinary soil.

at Ghur. The remaining two bays nearest the lock, down-stream, were of the best to be had from Sailamipoor, but which were inferior to those from Ghur. The grinding down of the brick-on-edge in these latter two bays is the greatest.

PILE-DRIVING 15 *feet piles of 5 inches square; average cost of driving one pile.*

Description.	Average number.	Rate.			Cost.			Remarks.
		RS	A.	P.	RS.	A.	P.	
Carpenters, ...	0·155	7	0	0	0	0	6·8	Labor for making tramways for pile engines, for each pile, rupees 0-0-2·88.
Smiths, ...	0·008	7	0	0	0	0	0·3	
Beldars, ...	0 050	6	0	0	0	0	1·9	
Ditto, ...	1·550	4	0	0	0	3	3·0	
Total cost Labor, ..					0	4	0	
15 feet piles, ...	1	1	0	0	1	0	0	
Iron ropes, oil, &c., &c., ..	0	0	0	0	0	0	4	
Total cost Materials, ..					1	0	4	
Total cost per pile driven, ...					1	4	4	

The rates are taken from one month's progress, during which 1,700 were driven.

A portion of the piles were driven by old engines at a rate of not less than 5 annas per pile, so that 4 annas is rather above what the rate should be with good working engines. The task with the new engines was 1 pile per beldar per day, or six per week. Smiths were employed in repairing rings for pile heads, &c., &c.

GRASSING *Puttrie Bunds. Progress in July* 1852.

100 feet distance.	6,24,790 superficial feet sirkundah, @	0	2	2	per 1,000.
50 „ „	3,58,900 „ doob, @ ..	0	10	1	„
	Total Rupees, ..	310	8	3	

Progress in August 1852.

150 feet distance.	42,548 superficial feet sirkundah, @	0	3	8	„
50 „ „	6,21,804 „ doob, @ ..	0	7	11	„
	Total Rupees, ..	316	0	0	

Grassing slope of mile 10; distance 300 feet. 14,145 superficial feet grassing with *doob*, @ 1-3-3 per 1000.

Navigable Canal slope.—Distance 400 feet. 3,634 superficial feet grassing with *doob*, @ 1-10-0 per 1000.

UMBALLAH, 10*th July*, 1867.

T. L.

No. CLXVI.

THE HINDOSTAN AND THIBET ROAD.

BY ARCHIBALD CREGEEN, ESQ., C.E., *Executive Engineer.*

IN the year 1850, when the new Kalka and Simla road was commenced, Mr. (now Sir) H. Edwardes, the then Superintendent of Hill States, submitted to Government a project for developing our commercial relations with Central Asia by way of the Sutlej Valley. Major (now Colonel) Kennedy, then Military Secretary to his Excellency the Commander-in-Chief, proffered his services as temporary Superintendent of the Hill Roads. An examination of the country north of Simla was immediately commenced: Colonel Kennedy reserving to himself the examination of the hills between Simla and Nagkunda, while Lieutenant (now Major) Briggs was deputed to report upon the country between Nagkunda and Thibet. The result of their joint examinations was, that a mathematical line of road, with especial reference to levels, was practicable; but that the construction of it would necessitate an enormous outlay.

As far as Soongri, seven marches beyond Simla, the line of country selected for the road appears to have offered little difficulty in determining. Advantage was taken of the continuation of the Cis-Sutlej main axis of snow; which, dividing the two great mountain torrents, the Sutlej and the Pabur, terminates in the plains at Kalka. It will be easily imagined that a continuation of this range must consist of very irregular peaks and depressions, diminishing irregularly as the plains are approached. One of the chief objects in the prosecution of the work was to keep as near as possible on the line of watershed; but this could not be done without forsaking the principle

laid down by Colonel Kennedy, viz., that the road should never rise or fall unnecessarily.

The original idea was to construct a road with a maximum gradient of 3 in 100, so as to be available at any future time for wheeled traffic. From Simla to Soongri, no bold features occurred (with the exception of the Sidhpùr cliffs) to interfere with the tracing of a line with a gradient of from 1 in 33 to 1 in 40. Beyond Soongri the main range had to be abandoned, for to follow it further only led to regions of snow; and it was now clear that the continuation of the road must conform, to a greater extent, to the contour of the spurs running out from the snowy range; while, at the same time, the intention of adhering to the watershed line would have to be abandoned.

Soongri ghât being a peculiarly obligatory point, Major Briggs endeavored to run a dead level line to the Nogrì river; but was met by cliffs of "adamantine granite," of 2 and 3,000 feet in depth. Failing in this he selected a site at an altitude to correspond with a site already fixed for the bridge across the Sutlej at Wangtù. This line necessitated the carrying of the road *viâ* Bàlì to the Nogrì river, for the last 7 miles of which it was to descend at a gradient of 1 in 33. From this point it was clearly Major Briggs' intention to run the road at a gradient of 1 in 35, so as to attain an altitude of about 6,000 feet,* whence, taking advantage of an easy line of country, he proposed to round the spur on which the city of Rampùr is built, but at an elevation of 3,000 feet superior to it; thence by a dead level line to the Syldung river, a distance of 25 miles, and finally by an easy descent to the Sutlej, a further distance of 8 miles, at a maximum gradient of 1 in 36.

Col. Kennedy's short but useful superintendence terminated between September and December 1850, and in the latter month Major Briggs assumed the direction. In the winter of 1851-52, the tunnel, 2½ miles north of Simla, 560 feet in length, along with several miles of road, was completed. This tunnel was driven through the solid rock, and was constructed almost entirely by prisoners, the night coolies only being free laborers, and a few of these assisted the prisoners in wheeling barrows during the day. In the excavation of this tunnel 10,000 prisoners and 8,450 free laborers were employed: "and taking," as Major Briggs writes, "the cubical contents of this excavation at 50,000 cubic feet (for it has not yet attained its ultimate dimensions

* The site fixed for the bridge was about 5,000 feet above the level of the sea.

of 12 feet in breadth and 20 feet in height), we have 2·71 cubic feet as the average work for each man. It must be remembered that every foot of excavation was through solid rock, of an unfavorable description for blasting, the geological formation of the hill being an indurated clay slate; and at the market rate the labor would have cost Rs. 1,057, but as a large amount of it was furnished as tribute, it only cost Rs. 391; a further sum of Rs. 220 was expended on artificers, so that the total cost of the tunnel to Government was Rs. 611." This work at the present day would cost little less than Rs. 15,000.

In October 1852, Major Briggs left for England, and Captain Montgomery officiated as superintendent. His report on the progress of the work in September 1854, states that on the 118 miles, from Simla to Seràhàn, divided into eleven sections, the state of the work was as follows:—

I. To Mahassù—10 miles; completed by Major Briggs.

II. Meog—11 miles; 2 miles completed by Major Briggs, and the rest by Capt. Montgomery.

III. Muttiànà—11 miles; finished partly by each officer.

IV. Nakunda—12 miles; finished partly by each officer; Captain Montgomery doing work on Muttiànà cliffs.

V. Bagì—9 miles; completed by Major Briggs.

VI. Kundrèla—9 miles; ditto.

VII. Soongri—9 miles ; 7 miles finished by Major Briggs, and 2 miles by Captain Montgomery.

VIII. Bàlì—12 miles; postponed.

IX. Nogrì—12 miles; completed by Captain Montgomery; continual bridging across chasms, cliffs, &c.

X. Dàrun—10 miles; cutting commenced. Nogrì river bridged by Captain Montgomery with red pine logs; spans of 60 feet. Blasting discontinued on cliffs near Nogrì, as heating the rocks with wood furnaces and pouring on cold water was found a more successful operation.

XI. Seràhàn—In progress.

Or, in other words, 80 miles completed and 35 miles in progress.

Major Briggs' intention to carry the road round the Rampùr spur was now abandoned; and Capt. Montgomery decided upon a series of zig-zags up the face of the entire hill to cross the Darum pass, urging at the same time the construction of a branch line to Rampùr.

Major Briggs, on his return from England, finished the road to 4

miles beyond Seràhàn, with bungalows at a distance of 12 miles apart, when the mutiny in 1857 put an end to operations.

Major Briggs' road for reasons above explained, did not touch at Rampùr, the capital of Bussahir, where is annually held one of the largest fairs in the N. W. Himálayas; and as all commodities from Spiti, Yarkand, and Thibet, &c., brought through Bussahir are transported to Rampùr, and there exchanged or sold to merchants from the plains, it is clear that any line of communication to develope the resources of these frontier districts should pass through this city.

Our relations with these distant regions will never extend so rapidly, as to require a road adapted to wheeled vehicles, while for generations to come, the transport of all merchandize will be effected by goats, donkeys, mules and yàks. Accustomed as these animals are to travel roads of every practicable gradient, without diminution of load, a direct line of road on the reverse of the principle advocated by Colonel Kennedy has been decided upon as more economical and better suited to the wants of all classes; and the Government on resuming the work determined to construct a mule road by the old line *viâ* Rampùr to join Major Briggs' road at Seràhàn.

This road is called the Sutlej Valley line, and in 1861 Major Nightingale was appointed to carry out this work. It descended with a very good alignment with an easy gradient of 1 in 10 to the left bank of the Sutlej, where on crossing the Bìrà stream it enters the territory of Bussahir; and following the course of the Sutlej through Nirt, Duttnuggur and Rampùr, abruptly ascends to Gaora; then crossing the spur on which the cluster of villages is built, descends into the Munglàd, and rises by a steep gradient of 1 in 5 to 1 in 3 to its junction with Major Briggs' road at Deo, two miles this side of Seràhàn.

With the exception of the new alignment of road from Sidhpùr to the bank of the Sutlej, this branch line, now the direct road, is merely a widening out of the old track that existed; and on the Gaora incline, where the gradients are steep, an entirely new alignment is desirable.

In 1862, Major Nightingale being compelled to proceed to England on medical certificate, Captain Lang, R.E., was appointed to the charge; and arrangements on a very large scale were made for completing the road to the frontier with the least possible delay. Large gangs of workmen and supplies were transported from the plains to Bussahir; and the works were, probably for the first time in their history, in full swing.

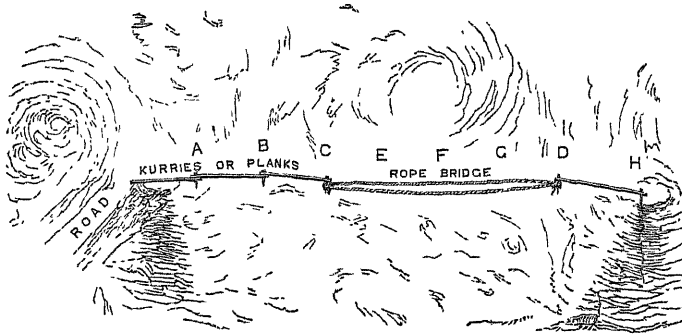
As far as Seràhàn it can scarcely be said that there were any difficulties encountered. The old track had been adhered to, and though the road passes through a very wild and rugged part of the country along the left bank of the Sutlej, where precipitous and barren hill sides are seen for miles, yet the line of country on the whole was favorable for road making. Beyond Seràhàn, however, every feature is changed. Where the old native track existed, it was found that along difficult and dangerous cliffs, natural ledges, projections or artificial staircases, winding up the face of a cliff, were the only means of communication available, the natives themselves having neither the appliances nor the inclination to make any improvements. On the easier portions of the road; even where there was no rock cutting new alignments were necessary, as the gradients adapted for goats were not suited for mules. In advance of Seràhàn, therefore, nearly one-half of the road is an entirely new alignment, remote from the old native track.

For a distance of 4 miles beyond Seràhàn, Major Briggs' road is retained. This road traverses the Hoomtì and Drali cliffs, and the cliffs in the Badar glens, and by the mule road. the Drali gallery, of 405 feet long, was the first one met with. By reference to *Plate* LV., the construction of a gallery will be readily understood. It consists of either 3 or 4 jumpers (according to the breadth of the cradle), let into the face of the cliff at an angle of about 45°. The jumpers should have a fair hold in the cliff of at least 2 feet or 2 feet 6 inches, and a projection from the face of the cliff of about 2 feet 6 inches or 3 feet, against which the struts of the cradles must rest, and if necessary be secured by a large spike passing through the end (flattened in this case) into the timber. For ordinary purposes, when the gallery passes along the face of the cliff, the section and scantlings, &c., as shown, will be ample, and it is only in such cases as a recess in the rock, or where a pier for a bridge is required on the face of a cliff, and the road inclines to it at an angle, that any modification of the example given is necessary. Such modifications as these can of course only be determined from an examination of the spot. The stirrups and horizontal pieces connecting the struts with the uprights should all be secured by iron straps or bands let into the cliff, and secured by lead. The cradles may be put up at convenient distances apart, there being no necessity for adhering to the same spans for the bays, provided that the distance be not so far increased as to necessitate heavier scantlings for some of the girders than for others. For a 6 feet road, there should be three girders, which

may either be placed the same distance apart, or the two inside ones placed closer to each other; for on the face of the cliff it will be found that decay will set in earlier in the inside one than in the outside one, on account of dripping water, &c., and it should always be an object to relieve it as much as possible of weight. The planked roadway should have a sprinkling of fine gravel thrown on to it; but as this is not always to be procured in the hills, a very thin layer of fine broken stone mixed with earth should be spread. If the gallery is not constructed with a uniform level throughout, but undulates according to the facilities for rapid construction offered by the cliff, thin strips of wood should be laid across, before having the earth spread; so as to render traffic more secure in wet weather.

Constructed as these galleries are on the worst description of cliffs, it is possible to get even large lengths of timber girders placed, but as the difficulty increases in proportion to the length of girder, it will be found seldom advantageous to use a greater span than 18 feet, while it is not improbable that in very bad places 15 feet will be more convenient. For expedition and simplicity of construction these galleries are admirably adapted for opening communication aross difficult cliffs. The great objection to their construction, however, if they are to remain semi-permanent structures to last a certain number of years, is, that from the perishable nature of the materials and their exposure to smashes, shakes and fractures from overhanging portions of cliff falling on them during the winter months, they require constant examination every year; and it is not always possible to detect any slight injury done them. They are, therefore, ill adapted for quick traffic. For slow traffic, however, they may be considered excellent substitutes for permanent roadways, and can be strongly recommended for adoption in a hilly country, where it is desirable to tap the recources of frontier districts; when, having secured the primary objects of the road, they could at any time be gradually dismantled and make way for solid roadways.

The crossing decided upon for the construction of a gallery across any cliff should be the one that contains the greatest number of broad natural ledges of a few feet in width, as the work can then be completed to each one of these ledges, thus forming a roadway for the transport of materials to the portion of cliff beyond. Having selected a crossing, the next operation will be to set men to work to fix the jumpers from which to suspend ropes and planks. Let it be required to cross a rugged perpendicular cliff,

say 100 or 150 feet to the first ledge. The first thing to be done is to get a good cliff climber to get out to A, where a hole will be bored in the cliff and a jumper let in. The cliff-climber will then endeavor to get to B, and repeat the operation, and so on with C. Between these jumpers, and

resting on them, a kurrie will be placed. But, supposing, there are fifty or sixty feet of smooth perpendicular cliff in advance of C, then the cliff-climber will scale the cliff to get to a place where there is standing room at D. At this point another bar will be let in, and a rope bridge suspended between these two points will enable men to be set to work to bore and let in bars at E, F, G, while the bar H will be secured at the same time; and thus a temporary line of communication will be opened across this portion of the cliff, and in advance of H the same operation will go on. Though this is an exceedingly dangerous operation, there are few good cliff-climbers who pride themselves on their activity and powers to climb to apparently inacessible places, that will ever hesitate to go wherever they can hang only their fingers and toes: and when once the temporary footpath, from 4 to 10 inches wide is opened across the cliff, an officer can then go and select the sites for the cradles. In some places perhaps, a kurree cannot be laid, and it will be necessary to lower or raise oneself by a rope secured to an iron bar let into the rock, some height above the proposed level of crossing. Great care must always be exercised in crossing this temporary footpath, for it not unfrequently happens that there is a sheer perpendicular drop of 500 or 1,000 feet below.

Beyond Seràhàn it is no unusual circumstance to find very precipitous cliffs, rising several thousands of feet above the Sutlej. Of these the Taranda, Wangtù, Neoza, Kashti, Maizong and Rogi cliffs are fine examples, and

"were more grand and dangerous than anything that had been before attacked in the construction of the Hindostan and Thibet road; and the first passage of the smooth water-worn granite face of the Wangtù cliff, rising like a wall from the foaming waves of the Sutlej as it rushes through the narrow Wangtù gorge, was a feat possible to but few men in the world, though unhesitatingly executed by the celebrated (in Bussahir) Bhulkù, who fixed in the crevices of the cliff all the first irons for the attachment of the ropes and planking, on which, suspended above the Sutlej, worked the coolies, who constructed the viaducts. Near Rogi also are precipices of stupendous height, scarcely to be surpassed in grandeur by any in the Himálayas; and to carry a road across their apparently inacessible face required bold and active hill men, careless of being perched on dizzy pinnacles boring for blasts; of being suspended on narrow planks, over "infinite space," or of crawling or creeping where there seemed no place for hand or foot to advance the work" *

The Wangtù cliff is very different from either the Rogi or the Maizong. The former, at the present crossing of the road, is perfectly water worn, and where in all probability the Sutlej rushed along some 500 or 600 years ago † with all the wildness and fury of the present day. After crossing the Wangtù bridge, this cliff is crossed at an elevation of from 80 to 120 feet above the Sutlej. The great difficulty in working this cliff was the comparative absence of all crevices, projections, ledges, &c., and the slippery surface along which men had to crawl. If a man had the misfortune to slip or make a false step, the chances were very considerably against his ever having an opportunity for another attempt. There is really and literally nothing on the face of the cliff that a man could hope to clutch, if he found himself in an awkward position; nor could assistance be rendered him if he fell. In an instant, the waters of the Sutlej would hurl him along, and he would be either dashed to pieces against a rock or large boulder, or be jammed between a couple of them. The Rogi or Maizong cliffs, on the other hand, are at an elevation of several thousands of feet above the Sutlej. They have, doubtless, been caused by immense landslips, and are very precipitous. On the Maizongs, a few sturdy pines are met with, but on the Rogi there is no vegetation visible excepting low down. These cliffs are rugged, many parts overhanging, and there are in many places drops of 500 feet, before touching another projection.

* *Vide* Capt. Lang's Report, dated August 1864, on Hindostan and Thibet road.

† The bed of the Sutlej I believe is lowered from 2 to 3 inches a year at Wangtù.

I have known an instance of a man from below Seràhàn walking across a portion of the Rogi cliffs on a 6 feet roadway, and falling over the cliff from dizziness in all probability;* but such accidents are rare. In these cliffs, though very perpendicular, there are numerous crevices in which to secure spikes; but then there is little or no standing room; in many places not more than is sufficient to rest part of the foot on. The great difficulty in crossing this cliff by galleries must have been the great liability of the men to accidents.

When it is known that the above-mentioned are only the finest specimens of cliffs between Simla and Pangi, and that there are numerous others more or less difficult to be crossed, it will be seen that in the distribution of large gangs of workmen along several miles of the road beyond Seràhàn, the necessity for rapid communication across the cliffs, for the transport of supplies to the party working in advance, it was imperatively necessary that this system of galleries should be resorted to. By this substitute for a solid roadway, cliffs likely to occupy the whole of the working season (only 7 months) in the construction of a solid and permanent roadway could be opened to traffic in a couple of months. This enabled the extension of the road to Pangi being vigorously pushed forward; and, accordingly, in the two seasons of 1863 and 1864, Captain Lang opened 57 miles of road, including seven bridges, numbered from 5 to 12 in Appendix B.

In *Bridges* that require more than simple wooden girders, one principle has hitherto been followed in their construction. This principle consists in supporting the roadway by large cantilevers built out of the abutments. The principle is one that has existed from time immemorial, throughout the N. W. Himálayas, where the want of skilled branches of trade has compelled the inhabitants to adopt the simplest forms of construction in their bridges or "sanghos." Very large and rapid rivers can be crossed very expeditiously, and more especially in bridges constructed by the natives, for these consist in having two large logs (round) laid between the cantilevers, 2 or 3 feet apart, over which loose slabs of wood or thick shingles are laid; and suspended, as they not unfrequently are, about 100 feet above the torrent below, they are sometimes unpleasantly elastic.

The accompanying drawing of the Wangtù bridge, built by Captain Lang, will best illustrate the construction of all works of a similar nature on the Hindostan and Thibet road. The span is 120 feet, divided into three bays

* In 1865.

of 40 feet each, the two end ones being supported by the cantilevers projecting from the abutments. The centre bay is an American truss, 45 feet in length, 5½ feet deep, and uniting with the wooden railings over the other two bays. The abutments are of dry stone very substantially bonded throughout by layers of wood running through the structure, not only strengthening the masonry, but keeping the ends of the cantilevers rigidly fixed. The foundations are on rock. At the toe of the right abutment a row of jumpers let into the rock secures the wood work from the effects of any sudden or extraordinary flood, such as that of 1866, which rose 26 feet higher than any flood previously known. Owing to the very awkward nature of the rock on the right bank, a cradle with heavy wood work and jumpers has been introduced. The elevation of the roadway of the bridge over the cold weather level of the Sutlej is about 70 feet; but in the rains this river rises to a height of 20 feet over winter level. From about 5 miles above the bridge, the Sutlej comes down with a frightful rush, the velocity in the rains being frequently over 20 miles an hour. This bridge is 120 miles beyond Simla and 176 miles from Kalka, at the foot of the hills, and considering the absence of skilled labor, and that nails, screws, and every little requisite had to be imported from the plains, the present structure appears to me to be the simplest that could be put up. The cost of the bridge with approaches, &c., was Rs. 10,000 only.

The year after this bridge was built, it was very nearly being destroyed by the falling of a large mass of detached rock, which destroyed the left abutment and approach. The rock in falling broke into smaller pieces, one of which fell upon the bridge itself. The rock fell from a perpendicular cliff about 1,500 feet above the bridge, and in situations like these, where it is impossible to provide against contingencies of this sort, it is very necessary in constructing a bridge, to put up one that can be easily renewed or repaired.

The road having been opened to Pangi, 157 miles beyond Simla, it was determined by the Government of India to limit expenditure on this road to the consolidation of the wooden galleries by blasted roadways, and Captain Lang having been transferred to Oude, I was appointed to the charge.

It was not proposed to dismantle or to substitute a solid roadway for the Wangtù gallery, and the Rogi cliff* being the most difficult on the line,

* The altitude of the roadway on this cliff is about 9,500 feet above sea level. In my official report t was stated at 1,000, which is an error.

it was determined to commence with it first. Previous to Captain Lang's departure, he had arranged for the blasting out of a pathway across the most difficult portion of the cliff, so as to keep open communication. In a distance of little over 400 feet, eight hundred mines, 2 feet apart, in vertical distance, were bored in 8 rows parallel to each other, and sunk at such an angle as to give a line of least resistance of about 2 feet. Along the level of the proposed roadway, a continuous row of mines,* 2 feet deep, and 1 foot 6 inches apart were bored, so as to determine if possible a continuous line of fracture. By the simultaneous firing of these mines, it was hoped that a break would be produced, and that we should be spared the necessity of resorting to very dangerous methods of working the cliff. How far we succeeded in our expectations may be realized from the fact that, instead of producing an impression upon the cliff, the cradles were smashed, and the staunchion bars twisted† and bent so as to be of no possible convenience to us. Immense quantities of overhanging rock were brought down from above, and the cliff itself was in as bad a state as at the commencement. In some places, a layer of rock, about 5 feet thick, gave way, and scaled down to a point considerably below the level at which the crossing for the road had been decided upon. Fortunately, however, from the method adopted in first constructing galleries along the cliff, there were several holes bored for holding jumpers, from which ropes were at once suspended and men set to work to bore as many more as were necessary to suspend sufficient men for the proper working of the cliff. When we succeeded in getting in a row of jumpers, from which to suspend the men, we crowded as many as possible on the work. The total length of this cliff in hand at the same time was between 300 and 400 feet, on the face of which from 4 to 600 men were suspended for a period of nearly four months, the number gradually decreasing as the roadway was worked out.

The Rogi cliff is of very compact gneiss. Its lamination is found in every direction, being either horizontal, circular, vertical or oblique. The most provoking part was that, for a long time, work it as we might, nothing but continual scaling occurred, which was trying to both temper and patience. It was certainly a magnificent sight to sit opposite to the cliff and watch these men working with apparently as much ease as if they were on a 6 feet roadway. But how much, indeed, depended upon the ropes on which

* These mines were not charged.

† The girders and planks were taken up before firing the mines.

they were suspended, for as many as fourteen men were sometimes on one plank and we were not over abundantly provided with rope to supply the place of pieces considered unsafe. Along the proposed level of roadway a row of crowbars was sunk, on which a kurrie or plank footway rested so as to allow of our crossing to inspect the work, as well as to enable the men to go backward and forwards. This footway was never wider than the breadth of a plank, and very frequently not wider than the breadth of a kurrie. Every day the direction at the mines had to be altered according to the result of the previous day's work; and, as a rule, nearly every yard in length required a different treatment.

Working as the men were on the face of the cliff and distorted as the lamination was, it was impossible to sink mines to suit each peculiar feature in the stratification; nor could the men themselves work in this position with much effect. The consequence was, that for a long time we had to submit patiently to a waste of powder, and a fruitless attempt to make an impression on the cliff.

As before stated, similar treatment could not be adopted throughout; where scaling went on, it was necessary to abandon any attempt at tunnelling or scooping out, and to cut down from a height of about 20 feet. The first mine by this arrangement generally produced a little scaling; another sunk immeditately behind, increased the line of least resistance; and after two or three mines were fired, scaling may be said to have stopped, and small mines and weak charges were then resorted to.

In places where the lamination was horizontal, the scooping out or half tunnelling commenced from near the level of the roadway upwards. But it was not always that the effect of the mines on the cliff could be noticed; and, as might be expected from the nature of the cliff, many mines were fired without the slightest result.

Our charges for blasting in ordinary places were $\frac{L.L\ R^3}{15}$ = charge in lbs., but as it was desirable that every stone disturbed in the cliffs should be got rid of, so as to reduce the necessity for the use of crowbars, which in many places could not be used, and in others not without the risk of their falling on one of the workmen, the charges were increased to $\frac{L.L.R.^3}{10}$, which worked with excellent effect, splitting the gneiss generally into small blocks, and throwing them clear of the work.

The result of my experience on the Rogi cliffs is, that it is always pre-

ferable to work from a certain height above the level of the proposed roadway; not only for the purpose of tunnelling out, but because the men are so much sooner able to obtain a footing on the cliff. This plan of cutting from a height of about 20 feet above the proposed level of roadway has been tried with excellent effect upon the Maizong and other cliffs, and is now generally adopted by us in all rock cuttings.

The Wangtù gallery is the only one existing on the road, and it is not proposed to substitute a solid road for this at present. In a road across any hilly tract of country, I hold it to be most important to place all galleries that are ever likely hereafter to be dismantled to make way for permanent roadways, at least 30 feet above the level of the proper crossing. By doing so there is no necessity for dismantling the roadway, and stopping the traffic, while from the staunchion bars on which the cradles rest, the men could all be suspended, and there would be a capital road for the transport of tools, &c., to any point upon the work. It is scarcely probable that the Wangtù gallery will be allowed to remain more than eight or ten years, when its place will then be supplied with a solid roadway. But it ought, unquestionably, I think, to be dismantled piece by piece (when the solid roadway is in hand), and reconstructed about 30 feet above its present level; for it would never do on a cliff of this sort to run the risk of any failure in even the smallest arrangements for the work. If the great advantages to be derived from reconstructing the galleries above the intended level of the solid roadway had been known to me before the work had proceeded so far, I should, without the slightest hesitation, as regards cost, have adopted this plan; for, after all, the cost would not have been large with the facilities afforded by the existing roadway for carrying out the work. It is impossible to over-rate the advantages to be gained from a good road in work of this kind, when there is a difficulty in carrying even a large jumper to some places.

With this exception (the Wangtù gallery) the road from Simla to Pangi is now consolidated throughout its entire length, and though liable to accident and injury from the falling of detached pieces of rock during the winter months, yet the cost of maintenance and repair will never be a large item of expense.

Appended will be found a list of all the galleries and viaducts dismantled, and the following are the quantities of work executed:—

Walling, ...	370,123 cubic feet.
Blasting, ...	348,570 „

the total cost of which has been Rs. 72,000. The blasting on the Rogi cliffs cost on an average Rs. 20 per running foot for the whole of the cliff; but there were portions that cost over Rs. 40; whilst the average of the Maizong cliff, of the same material, but differently stratified, was Rs. 12 to 15 per running foot. On these cliffs there were a few places where the cost was about Rs. 30 per running foot. By cubic measurement, the cost of blasting on the cliffs was nearly Rs. 15 per hundred cubic feet, and of walling from Rs. 5 to 8 per 100 cubic feet.

The cost of the 57 miles executed by Capt. Lang, was	Rs.	3,38,835	0	0
The cost of improvements to 40 miles from Sidhpùr, to Seràhàn, was - - - - - - - -	„	22,500	0	0
Cost of replacing galleries by solid roadways, was	„	72,000	0	0
Making a total expenditure of	Rs.	4,33,335	0	0

or of Rs. 4,333 per mile. When it is considered that the pay of a coolie is Rs. 8 and 10 per month, and skilled labor proportionally large, the cost per mile is not great. No records exist to show the expenditure on the 44 miles from Simla; in those days labor was cheap, and the cost of the 44 miles may be taken at about Rs. 1,500 per mile.

Beyond Seràhàn the bridges over the torrents are liable to be washed away at any time, for they have to accommodate the passage of large avalanches in their descent from the snows above. In 1866, the Chownda bridge, of 35 feet span, was carried away during the night. It was built on two immense blocks of stones for abutments, and though the weather was all that could be desired, yet no one ever found out the cause of the sudden disappearance of this structure. In the morning a well defined water line about 8 feet high was visible on the banks; and the abutment boulders, about 25 or 30 feet in diameter, and the bridge were gone. The only cause that I can suggest for this is, the probability of a large avalanche having become wedged in between two cliffs in the snowy ridge which supplies this torrent; and the pressure of a large body of water dammed up, must have caused it to burst and come down with overwhelming violence, and wash everything into the Sutlej. The Yoola bridge, of 40 feet span, was carried away in 1865 by an avalanche more than half a mile long, and over 100 feet thick, which remained below the site for 12 months before it melted. As it gradually disappeared large trees, and rocks were constantly exposed, while the forest above, through which it had passed, had the appearance of having lost many a fine deodar. The

trees were cut off nearly level with the ground, and in the distance the section appeared as clean as though they had been sawn. While this avalanche remained in the bed of the torrent, the Yoola had worked an arch out for the passage of its waters, and during its existence it formed, what is frequently met with in the interior, a snow bridge. It was also a favourite halting place for shepherds and traders, and on the surface might be seen several groups of figures sitting around their respective fires.

It is not improbable that before long, the extension of the Hindostan and Thibet road to the frontier will be again vigorously pushed forward. Indeed, it can scarcely be imagined how little utility there is in the road in its present state, excepting to the villages through which it passes; these it has benefitted to a very considerable degree, and considering that 7 or 8 more marches only require to be done to carry the road to the Shipki terminus, no return for the outlay can ever be realized until the objects of the road are partially developed.

In the construction of this road beyond Pangi there will not be the necessity for the steep gradients that exist on some portions of the road between Rampùr and Wangtù. Before adverting to the line of country to be traversed beyond Pangi it will be necessary for me to state the conditions to be fulfilled in the construction of a mule road across the Himálayas. 1st, Shortest distance, with a maximum gradient of 1 in 5 to 1 in 3, the latter for short lengths only; 2nd, The avoidance of zig-zags where possible; 3rd, That where it is necessary to cross a spur or ridge on account of cliff, and steep gradients are resorted to, it is desirable to break the gradients by horizontal runs, so as to ease the beasts of burden; for it should be remembered that the natives of these parts do not regulate the loads on their animals upon any calculation of the steepest hill. Rather, they consider the difficulty of the march before them, put on a maximum load, and make due allowance for the time to be occupied on the journey. As they only travel a march a day, it matters little whether the time occupied is four or twelve hours; 4th, A road to be of the greatest utility to a hilly country should be constructed at such elevations as are below the limit of snow, which may be assumed at 12,000 feet above the mean sea level.

I must not omit to state that large flocks of goats are infinitely more destructive to roads than mules; and if a Kunnawurì can find out a path likely to shorten distance ever so little (no matter how steep the gradi-

ents so long as the loads have not to be taken off the animals) portions of a level road will be abandoned. But though they are always ready to forsake an easy portion of road, their own tracks are not always the shortest; for unable as they are to open communication across a cliff, they will dodge in and out in a very circuitous way so as to take advantage of the least difficult portions; and the construction of a road along the face of one formidable cliff will often save endless smaller difficulties, and be more economical. It would, however, be impossible to lay down any rules for guidance in a country of this sort, where every spur presents an entirely new scene; and the several difficulties should in every case be disposed of by an officer on the spot, whose observation and knowledge of the principles on which the construction of the road is based, will nearly always ensure the best direction and the most economical route.

In order that the road may never attain to a greater elevation than the limit of snow, it will be necessary in advance of Pangi to follow the course of the Sutlej throughout its entire length to Shipki. Otherwise, there is at present a very fair track for goats (with the exception of the passes) by way of the Gongra, Rohung and Hungrung passes, of 13,500, 14,350 and 14,530, feet, respectively, above the sea level. This, however, never can form a route for a trunk line of communication. When I returned from the frontier at the end of May this year, and although there had been an exceedingly mild winter, yet yáks could not ascend the snow with even light loads upon them, and though the snow early in the morning was exceedingly hard. Snow begins to fall upon these passes in November, and if we assume that in ordinary seasons the snow is not melted away until the end of July, there are only three months remaining during which animals larger than goats could cross the passes. A road by way of these passes, would, however, to be of utility for three months in the year, have to be considerably lengthened; and if the gradients were under 10 in 100, according to Captain Lang, the present distance would be increased 8 times;* while if the gradients were 1 in 8, the length by this route would be longer than the continuation of the road by the Sutlej.† By the Sutlej valley route the highest elevation that would be attained is 10,100 feet above the level of sea, and this at Chango, the N. W. terminus of the road. At intermediate points, the level or altitude of the road would range be-

* *Vide* Captain Lang's Report, August 1864.
† *Vide* Colonel Hutchinson's No. 626, dated 26th September, 1864.

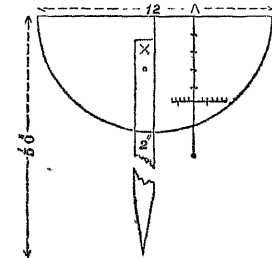
tween 8,700 and 9,300 feet above the level of sea.* Between these limits too, snows falls very lightly; and with the exception of a month or so in severe weather, the road will be available for traffic throughout the year. This is an object of such importance that the summer route *viâ* the passes could never be of any practical utility in developing our commercial relations with Chinese Tartary, and any attempt to continue the road by this route must be given up.

By the Sutlej valley, the Hindostan and Thibet road will pass through the large and populous villages of Rarung, Akpa, Yangi, Lubrung, Kànam, below Shassù, Spooi Khàb and Numgea with a line to Shipki, and a branch line up the Spiti river below Nàko into Chango. With the branch line to Chango, the total length of road yet to be constructed will be about 90 miles, and as far as gradients are concerned will be exceedingly easy.

In the first march from Pangi to Rarung the road will start at an elevation of 8,971 feet above the sea, and will undulate throughout its entire length. The gradient will, however, be very easy—the steepest occurring where difficult cliffs are met with, and these will not exceed 10 in 100. The road across the Kashung cliffs, as, indeed, the whole march, was lockspitted† by Capt. Lang before leaving the road, and the solid roadways are now being worked out across them, and by the end of November $3\frac{1}{2}$ miles of road will be completed. On this march there will be only one torrent to bridge, which will be crossed by a bridge of wooden girders resting on cantilevers. Beyond the Kashung torrent, the road will cross cliffs for another couple of miles, and then descend into Rarung at an elevation of 8,792 feet above sea level. With the exception of about 5 miles, the remainder of this march will traverse a fair line of country.

In the second march from Rarung to Tangi, the road will pass through

* By boiling apparatus. These heights will be found to be pretty correct.

† A lockspit or tracing of the road is set out by an exceedingly simple instrument, a sketch of which I give. The semi-circular portion is made out of the head of a *powder barrel*, or $\frac{3}{4}$-inch plank and may be 12 or 13 inches in diameter. It is fitted into an upright and secured by a screw, so that the centre of the semi-circular piece may be on a line with the inside of the upright. At right angles to the diameter of the semi-circle there is a scale of 5 inches divided into 20 parts to the inch, or 100 parts in all. At right angles, and at the end of the 5 inches, a scale of 1 or 2 inches on each side, similarly divided should be made. From a little notch in the top suspend a plumb-bob, and by moving the semi-circular piece on its axis a gradient of any number of parts in 100 can be attained. The addition of a couple of spirit bulbs would make this a very handy instrument. For setting out steep gradients for a mule road it is practically correct, a simple cross headed staff is all that is required, and gradients can be set out wherever a man can stand.

a country favorable in every way to road making. From Rarung to Akpa the road will be constructed in the *debris* of one continuous landslip of about 4 miles in length. The road will flank the Gongra range, and far up the mountain side nearly all the way to Jangi continuous unbroken lines of mural cliff can be observed, which, judging from the appearances of the trees, must have been occasioned by immense landslips about 100 years ago. The road will descend on this march about 200 feet in 10 miles, and will enter Jangi at an elevation of about 8,500 feet above the sea.

In the third march from Jangi to Kanàm, the road will descend to the Asrung river at a gradient of from 0 to 10 in 100. Here a cantilever bridge, about 50 or 60 feet span will be necessary. The road should then avoid any zig-zags up the Toolnurrung pass, as the hill side is exceedingly steep, and should flank the spur overlooking the Sutlej at a gradient of about 1 in 10; then descend for a short distance and again ascend into the village of Lubrung, and on, at nearly a level, to Kanàm, a large town containing six prettily situated hamlets. The elevation of the road at this point will be about 9,000 above the sea.

In the fourth march from Kanàm to Shassù, the great object will be to run the road for 7 miles at a dead level, or with a very slight descending gradient, so as to touch the confluence of the Thanam with the Sutlej. The road should pass below the Keelnarung pass, or winter route, and will, up to this point, be easy. At the turning into the Thanam river, and for several miles up the right bank are the Nardhung (*dhung* being cliff) cliffs, of stupendous height, rivalling the famous Rogi cliffs. These cliffs should be avoided at all risk, for it is my opinion that nothing short of a road entirely blasted out of the cliff without any walling will ever remain long upon them. On the march between Shassù and Spooi, I had a fine opportunity for reconnoitring these cliffs, and during the night at Shassù and the morning of the following day, piece after piece of detached cliff was bounding down the hill side; anything save the most solid and durable work would stand a poor chance of a long existence. On these cliffs there is no earth or vegetation, save a few stumpy deodars and Neoza pines (*Pinus Gerardinana*), which are stern and strong enough to withstand the severity of the weather. On this march, as, indeed, on the previous one also, the trees are very dwarfish, and high up, are only the size of large bushes. To the deodars (*Cedrus deodora*) there are no straight stems and wide spreading branches. They are dwarfed from their roots, and spread out into 4 or 5 stems, all stunted in their growth,

and of little or no use for building purposes. The cost of a permanent road across these cliffs, so as to bridge the Thanam higher up and to touch at Shassù, would be enormous. It will, therefore, be better to cross the Thanam river somewhere near to its junction with the Sutlej by a bridge of one span of about 180 or 200 feet; and then to run a branch road at a very trifling expense to Shassù. The elevation of road at this point will be a little under 9,000 feet.

In the fifth march to Spooi, the road must be taken across the cliffs, which here line the right bank of the Sutlej in magnificient wildness. The native track across these cliffs, about 1,500 feet above the crossing for the Hindostan and Thibet road is considered the worst footpath in Bussahir. This march, will, I think, be the most expensive on the road; the whole of the cutting will be through hard rock, which will be difficult and tedious; the length of it will probably be about 6 or 7 miles. Along this march the road will undulate and finally descend to the Sutlej below Spooi (about 900 feet) at the Namptu Sangho, or cantilever bridge, at an altitude of about 8,500 feet above the level of the sea.

In the sixth march to Numgea, the Sutlej must be crossed—the site for this will be the present site of the Namptu Sangho, the span will be 115 or 120 feet, at an elevation above the winter level of this river of 120 feet. The road will traverse a fair line of country along the left bank of the Sutlej. The scenery on this march is very wild; the right bank being large mural cliffs of granite without a blade of vegetation upon them, and rising almost perpendicular from the Sutlej to the confluence of the Spiti river, and then extending up this river almost the whole way to Li. At Dabling, I believe, there are a few deodars and poplars (the latter is not indigenous) of fair size, but with this exception wood is exceedingly scarce. The mountains all around are very high and precipitous, and in front are the Perguil peaks, the frontier boundary with Thibet, rising to a height of 22,227 feet above the sea. The absence of the fine lofty pines Lower of Kunawar* gives the scenery in these regions a peculiarly cold and wild appearance. The road will ascend to the village of Khah, and then descend to Numgea, at an elevation of about 9,200 feet above sea level.

In the seventh march to Shipki in Thibet, the road will be carried along very precipitous cliffs. At present the terminal point is not decided upon, as the road will only pass for a distance of four miles in the territory of Bussahir; the remainder of the march will be in Little Thibet. This portion of the road will be difficult.

* Bussahir is divided into two provinces, Upper and Lower Kunawar.

The branch line to Chango will leave Numgea, descend to the Sutlej, and crossing that river will run through some stiff granite cliffs that line the right bank of the mouth of the Spiti river; thence through an easy line of country with an ascending gradient passing about 1,500 feet below Nako (elevation 11,741 feet above sea level), a large village built at the limit of snow, and finally into Chango, at an elevation of about 10,000 feet above the level of the sea.

Here there is a large fair held in September, and it is proposed to give facilities by an easy road to merchants from the Punjab to go thither and make their own purchases of "pushm," a fine sort of down obtained from Thibetian sheep and goats, and used extensively in the manufacture of Cashmere shawls, &c. At present the trade passes through Cashmere.

In the extension of the road to the frontier there will only be three bridges of importance, viz., the Thanam of 200 feet span; the Namptù of 115 feet; and the Numgea of 90 or 100 feet span. In a country destitute of timber, where its importation would be not only an expensive item, but almost an impossibility in large and heavy scantlings, light iron suspension bridges are, I think, unquestionably the proper things. For the Namptù and Numgea sites, there can be no question about their adaptability, for the former is far removed from any cliffs where the descent of a detached piece of rock would be likely to damage it, and the latter would I thing be quite safe, since the present twig bridge has existed long enough to rot without sustaining a single accident. For the Thanam bridge, however, there will I apprehend be some difficulty in selecting a favorable site, but it should only be decided upon after careful observation, extending over a period of at least a couple of years.

The extension of this road is now in hand for the current year, on a small scale. If the Government of India lend their full support to the carrying out of this project to the frontier, without interruption to the work, the year 1870 or 1871 will, I hope, see the work completed. There will then be two points of communication with Chinese Tartary, and two outlets for the trade which is now carried northwards through Ladak and Cashmere, for want of proper communication on this side of the Punjab. Without the extension of this road there is no inducement for traders to export in very limited quantities their *real* pushm *viâ* Bussahir; hence the so called pushm met with at the Rampùr fair is no more worthy of that name, than hair is worthy of being called wool. The fact is, that this pushm is nothing more than the fine down obtained from Kunawar goats and sheep, and mixed with the outside hair and wool, and the whole transported to

Rampùr under the name of "pushm." This fine down obtained from the Thibetan goats is much finer than can be obtained from any other sheep or goats in the neighbouring hills, and the staple is longer. These are two important points in real pushm, and can only be obtained from animals that are fed on rich pasture lands with a high elevation and dry climate. Besides pushm, there will be a large trade done in borax, wool, Yarkand churrus, blankets and goodmàs, when once a through line of communication is established across the N. W. Himálaya. A road of this kind cannot fail to develope the trade of a country whose race is unknown to us, and the fact that the border men will be only too ready to avail themselves of the facilities offered for transport will do much to facilitate and enhance the value of our commercial relations with Thibet.

It is impossible to frame an estimate for the continuation of the road, but the probable expenditure will be about 5,00,000 Rs.

A. C. C.

SUBATHOO, 10*th August*, 1867.

APPENDIX A.

List of Galleries and Viaducts dismantled on the Hindostan and Thibet Road during 1866-67.

Mile from plains.	Mile from Simla.	Name.	Gallery length.	Viaduct length.	Remarks.
				cub ft.	
153	97	Hoomti cliff, ...	...	43	
154	98	Diali ditto, ...	405	...	
155 158	99 to 102	Badàu glens, ...	180	243	
159	103	Chòra clift, ...	90	...	
165	109	Tarunda ditto, ...	247	168	
166	110	Ditto, ...	...	81	
170	114	Soongri ditto, ...	150	...	
176	120	Wangtù ditto, ...	...	45	
177	121	Wungui, ...	40	...	
178	122	Sutlej bank, ...	150	...	
185	129	Ditto, ...	...	22	
187	131	Oorni cliff, ...	...	100	
189	133	Mèrù,...	...	84	
190	134	Kashti, ...	...	190	
191	135	Kashti cliff, ...	60	...	
194	138	Maizong, ...	469	319	
195 196	139 140	Ditto, ...	336	639	
198	142	Rogi, ...	420	312	
		Total, ...	2,547	2,246	

2,547 Running feet of galleries dismantled.
2,246 " viaducts ditto.
4,793 " wooden structures replaced by solid roadways.

List of Bridges on the Hindostan and Thibet Road.

Number.	Name of bridge.	Span. (feet).	Remarks.
1	Bera, ...	30	Cantilevers from abutments, built in 1866.
2	Muchara, ...	35	Do, do, do, 1866.
3	Nogrì, ...	68	Do, from Rampùr abutments, built in 1864.
4	Pushàda, ...	50	Do., do. do, 1864.
5	Munglàd, ...	56	Do, from Seràhàn abutments, built in 1863.
6	Chownda, ...	36	Do., Tarunuda abutment, ditto 1866.
7	Syldung, ...	58	Do, do, do, 1863.
8	Wangtù, ...	120	Do., both abutments, one span, ditto 1864.
9	Wungur, ...	140	In three spans, built in 1864.
10	Yula, ...	40	Built in 1865.
11	Runung, ...	47	In two spans of 12 and 35 feet, 1866.
12	Mulgaon, ...	90	In three spans 20, 40, and 80 feet, 1864.

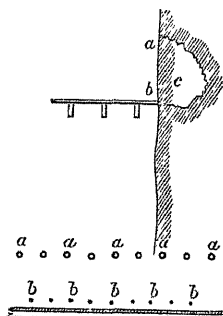
Specification for Consolidating Wooden Galleries, by Capt. A. M. Lang, R.E.

Masonry—In all localities where, in the following detail of measurements, the work "to be done" is specified as "to be built up;" the first operation will be to lower men to the specified depth, either by scaffolding from below, or on planks, or by ropes secured to the bridging above, and to carefully blast out a ledge or succession of ledges at least 3 feet wide, on which to found the lower courses of masonry.

Walling—When the foundation ledges are constructed to the satisfaction of the officer in charge of the work, the walling will be commenced and carried up course by course, truly level, facing and backing identically built and brought up level together: the largest stones to be used in the lowest courses, and the lightest for the highest.

Stone.—Stone employed to be granite, gneiss, or hard durable mica schist, according to the nature of rock existing in such locality. Stones to be roughly hammer-dressed, and laid truly on their natural beds.

Batter or Bond.—The walling will be built either with a batter produced by 3-inch off-sets in every 2 feet of height without timber bonding; or (in case of very high walling) with a smooth face, and deodar timber bonding of heavy scantling, as decided in each case by the Executive Engineer.

Blasting out Roadway.—Where in the detail of work it is stated that the new work is "to blast out the roadway;" a new roadway 7 feet clear in width is to be provided on the present level, and shall have the cliff on the inside so scarped or tunnelled out to such a height as to admit of the safe and convenient passage of a man on horseback. Meanwhile, the roadway (in every case, a timber gallery projecting over the cliff or a timber viaduct bridge spanning some bend in the cliff) must be retained passable for traffic.

The conditions above specified must be rigidly complied with, but the exact mode of operation will differ almost in every case, and must be decided upon and superintended by the officer in charge of the work. In some cases the work will be commenced with very small mines, bored 2½ or 2 feet above the roadway, and bored obliquely into the rock, which will be fired one by one, the roadway about the spot being guarded by logs of trees, and very small charges being used in the mines, to compel the rock to split true to the road level; horizontal mines *b*, *b*, will be driven

in at road level, but not loaded, the charge being put into the oblique mines, *a*, above them, so placed that an oblique mine, *a*, shall be bored in the interval between two horizontal bores, *b*, *b*.

In other cases a very large number of horizontal and oblique mines will be bored into the cliff from the road level to 15 or 20 feet above it; and when all the mines have been bored and loaded, the planks and girders of the gallery will be removed, and all the mines fired in large batches, until the whole number have been discharged. The shattered rock will be removed by crowbars, sledge hammers, &c., and the roadway of the gallery will be again constructed for traffic while additional mines are being bored to complete the blasting out of the road.

ABSTRACT OF ESTIMATE.

Sub-head.	Quantity.	Rate.	Cost.			Remarks.
			Amount.	Total	Grand Total.	
	c. ft	RS.	RS.	RS.	RS	
Blasting out roadway, ...	2,32,340	12 per 100	27,881			
Walling, ...	2,46,749	8 per 100	19,740	47,621		
Contingencies, at 5 per cent., ...			2,380	2,380	50,001	

Rs 20,000 to be paid in cash.
,, 30,000 to be paid in supplies.

THE WANGTU BRIDGE—*Report.*—The point at which the road through the Sutlej valley, from Simla, Rampùr, &c., to Shipha, Shialkur, and the Chinese Frontier, crosses from the left to the right bank of the river, is named Wangtù. At this point there is no village, but two routes here meet the Sutlej valley road One, from the north, leads over the Tarie pass from Spiti; the other (but seldom used), from the south, leads from Pahu and Tonse valleys, and over the Shaitoot pass. At Wangtù the altitude of the river above sea level is 5,000 feet. The river rushes with violence through a narrow gorge between cliffs of granite and gneiss, which gorge at its narrowest point is about 90 feet in width. The cliffs are very lofty, perpendicular and smooth; water-worn for many hundred feet above the present level of the river. The present bridge is erected at an admirable site: not at the narrowest spot, where the precipitous cliffs preclude any easy approach, and afford no room for building operations; but at a point where the span is 136 feet, and the natural rock abutments stand well above flood levels, and are ledges, distinct, and far from the cliffs, which recede from one another rapidly below the lower (western) end of the gorge: the present bridge is of "sangho" construction, old and in decay, narrow, and too weak to bear anything but foot traffic, goats, &c.

The question of a site for a new bridge has been carefully considered and discussed, and probably no better site could be selected than that now decided upon.

It is about 100 feet lower down stream than the present one, on the same ledges of granite rock, and at a point where these approach within 102 feet of each other.

No site affording any reasonable span, and sound foundations, occurs near Wangtù lower down the river ; and higher up the stream no span of less than 200 feet could be obtained, except in the middle of the gorge, where there is no room for building. *Above* the gorge (except at the site below noted) high cliffs rise abruptly from the river on the left bank, and no object would be gained by blasting a road across them, with a view of crossing higher up the river, where no decrease in width occurs for many marches.

Just above the gorge, a site could be obtained of somewhat over 200 feet span, and were a bridge built here, the passage of the Wungur and the cliffs beyond would be saved. But the traffic of the Taric pass route from Spiti would be lost ; and, moreover, the saving of the cost of these works would be counterbalanced by that of the bridge of double span, which would occupy two or three years in construction ; would need skilled labor of all kinds imported from the plains and would require masonry abutments of the very best stone and lime (resting as they would on shingle and boulder foundations, exposed to the action of the stream instead of being raised above flood level on granite rocks) Under these circumstances, considerations of economy would lead to the preference of a bridge of 102 feet span over the Sutlej, another over the Wungur, and the passage of the cliffs, to a bridge of 200 feet (or more) span, with the inferior advantages of foundation site. Considerations of rapid execution are entirely in favor of the former, which could all be completed in one working season.

The site being thus decided, the style of construction remains to be settled.

Under the circumstances—viz., timber of large scantling in abundance, and want of skilled labor, the employment of the *sangho* principle suggests itself as most feasible. But to improve the defects of the untied cantilevers of the hill construction, and of its sloping roadway, it is proposed to tie the extremities of the upper cantilevers to the abutments, by horizontal (lattice) girders ; and to span the interval also by lattice girders. The violent hurricanes of wind which rush through the gorge render the employment of a deep and heavy lattice dangerous: a low American "resultant truss" is therefore proposed, with all the ties of iron. Calculations for all the scantlings of the truss are annexed; and also for the compression of the cantilevers. To render the cantilevers more rigid, and to form them into a system of framed levers, vertical stirrup pieces are attached to the outer cantilever at intervals of 10 feet. The lower tier of cantilevers is placed at an inclination of 25° for greater strength ; but to lower the elevation of the roadway, the two upper tiers are placed at the minimum incline for struts, viz., 11°. Heavy scantlings of deodar are to be laid across the cantilevers throughout the whole width of the abutment, and tied down to the rock by iron stays.

On the left bank of the river, the section of the rock is as in *Plate* LVII. It is thought advisable to refrain from throwing the whole weight of the abutment above the projection B ; and yet the great advantage of 10 feet less bearing cannot be foregone. Consequently, while the abutment is built at A, a system of staunchion frames is erected at B, to carry the lower tier of cantilevers. All further details are shown in the *Plate* and specifications.

The *rates* of the estimate are as low as can be possible assumed; all the timber having to be brought several miles from the Shaitool pass forests by *no* roads; and labor being now more than double that obtaining in Captain Brigg's time.

SPECIFICATION.

Blasting.—For the foundations of the abutments, the surface of the rock at site to be blasted, until a tolerably even surface, countersloping from the river, is obtained. The largest and best of the stones detached by blasting (granite) are to be roughly dressed, for employment in the outer course of masonry.

Masonry.—To be throughout of granite, bonded with deodar. No timber to be introduced until the masonry is 8 feet high. the largest dressed stones being used for the lower courses; carefully laid horizontally and breaking joint. Abutments, approaches, &c., to be of the dimension specified in details and *Plate.*

Cantilevers—To be of round deodar timber, of well grown, sound, mature trees, of the exact length shown in *Plate:* none to be of less mean girth than 3½ feet, or of less small-end girth than 3 feet. The lowest tier to contain trees of not less than 4½ feet mean girth. The lowest tiers to be laid at 25° inclination. The two upper tiers to be laid at 11°. A bearing plate, 12 × 12 inches, to be laid across the heads of each tier of cantilevers, one foot from their extremities, to carry the next tier. All tiers to be connected, at 10 feet intervals with vertical stirrup pieces, as shown in *Plate,* strapped to the outer cantilevers by bands of iron 3 inches wide by ½-inch thick. All to be pinned to wall plates (two or more) 12 × 16 inches, imbedded in the masonry, and to have their extremities tied into the natural rock by 1¾-inch iron bars.

Lattice Girders.—The cantilevers to project 34 feet from the right, and 33 feet from the left, abutment, and across the space then left of 40 feet, two lattice girders to be thrown, and carried continuously to the abutment · to be 9 feet apart in the clear. Dimensions of chords, braces, and ties, to be exactly as fully specified in detailed drawings, calculation and estimate.

Timber.—The timber throughout the bridge to be of deodar: excepting only the abutting pieces of the lattice, which are to be of *yew.*

Iron.—The iron ties to be of ¾ inch and ½-inch round iron, driven through slightly smaller augur holes. Heads to be 2 inches square by ¾-inch thick, and to be firmly fastened on. Nuts of same dimensions as heads, and each provided with a washer 3 inches diameter and ¼-inch thick.

Roadway—To be of 3-inch deodar planks, spiked on to joists, 7 × 4 inches, which shall rest on, and be spiked to, the lower stringer of each lattice girder.

Staunchion Frames.—On the projecting ledge below left abutment, the lowest tier of cantilevers to be laid on a set of 7 staunchion frames: their lower ends being connected by a heavy beam laid on them, and pinned down to the rock by 1¾-inch iron bars. The staunchion frames to be formed as shown in *Plate.*

At 2 feet intervals, iron staunchions, 3 inches diameter and 8 feet long, to be driven as jumpers to a depth of 3 feet into the rock, at an inclination of 45°: a beam 8 × 6 inches, is to connect their upper ends. Within, and at the foot of these, a beam 24 × 24 inches and 14 feet long, to be laid on the rock, and pinned down by 1¾-inch iron stays. On this beam to be framed 7 pairs of diverging struts, 12 × 12 inches, each pair opposite to a staunchion: the heads of each pair of struts being connected by a tie 12 × 7 inches and 8 feet long. Two bearing plates to be

laid across the heads of the struts: on to these the lower tier of cantilevers to be bolted.

Approaches.—On the right bank the approaches to be carried across the present level of rock: but on the left bank a masonry wall, 12 feet wide, to be carried across the low ground between the present road and the island rock, on which the left abutment is built. This will be 150 feet long, at a gentle curve and of height varying from 6 feet or 24 feet in height.

The bridge was completed for about Rs. 10,000.

No. CLXVII.

DISTRIBUTION OF CANAL WATER.

To the Editor.

DEAR SIR,—The enclosed paper, on the distribution of canal water, was written two years ago. At that time, however, I had scarcely a six months acquaintance with canal work, so I thought it premature to make public suggestions that further experience might show to be impracticable; but I still find that my ideas on the subject have undergone but a slight change. I do not *now* advocate that any one scheme to the exclusion of all others should be adopted in the distribution of canal water; on the contrary, the irrigation of each village should be arranged for separately, so that every advantage might be taken of local peculiarities; for this reason, the scheme here set forth would appear applicable only to cases where the full supply line of the rajbuha is scarcely above the natural surface. I purpose to treat of arrangements for the distribution—(i), Where the water has to be raised; and (ii), Where the rajbuha is wholly in embankment, in a separate paper.

To the objection that it would be a gigantic task to go into details for each village, I would answer that the improved methods should be introduced gradually, and first in the older irrigating villages, where the men have had experience in managing water, and knowing what they wanted, could afford valuable assistance to canal officers in carrying out a new scheme. Besides, an inspection of existing water-courses would diminish the work considerably.

If a few villages were brought under the new arrangements, year by year, and duplicate copies made, where there were any modifications of the ordinary procedure, no confusion need be the result. And having found

out practically what systems were most adapted to particular localities, one of the establishment, with a few Irrigation Surveyors, might be specially deputed to the re-modelling of the irrigation of every village.

E. S.

May, 1867.

Distribution of Canal Water.—The different plans proposed for realizing water-rents may be divided into two classes—(i), Those having for their object a cheap and expeditious method of charging for water supplied, according to the area irrigated, with or without discriminating rates; (ii), Those by which the volume of water actually taken is charged for at a fixed rate for a certain volume, as 1 rupee per 40,000 cubic feet.

The systems at present in force, on all canals in the North West and the Punjab, belong to the 1st Class, and with unimportant and slight differences in detail, the following sketch may apply to all.

The zemindar pays a certain sum per crop, proportioned to the area irrigated; the number of waterings and the quantity expended in each watering, are not taken into consideration. Each rajbuha is divided into beats, varying in length according to the demand for water. On each of these a chokedar is placed, whose duty it is to keep an account of every field irrigated, and to report any infringement of the canal regulations. A chokedar's beat varies from 5 to 8 miles in length; and taking into consideration that the irrigating outlets in many of these beats often number as many as 25 to 35, with water-courses from 1 to 2 and even 3 miles in length, and that the boundaries between the different fields are often scarcely noticeable, and always changing, it may be imagined how untrustworthy the results obtainable are. After each season, or "fasl," measuring parties are sent out. In the case of the rubbee crops, the work begins about the middle of January; and for the khureef about the middle of August. In each party there is one mohurrir and two chainmen, and they are accompanied by the lumberdar and patwarri of the village, the owners of the fields and the chokedar. Each day's work is signed by the lumberdar, chokedar and mohurrir; then sent on to the zillahdar, who after verifying the papers, signs and forwards them on to the Executive Engineer, in whose office an abstract is prepared of the amount due by each irrigator; and on these abstracts the Deputy Commissioner of the district realizes the revenue, in instalments at stated periods.

The disadvantages of this system are evident; for there is scarcely a satisfactory check on the work of any one of the many men employed. Nor is any inducement held out to the zemindar to make the most of the water. Besides, it entails the keeping up of a large revenue establishment, and gives rise to numerous law-suits and disputes. And when the supply in the canal is not sufficient to meet the demand, any amount of care and energy will not ensure a fair division, and every inducement is given to bribery and corruption.

It has been suggested that it would be preferable to make *accurate* surveys of the lands receiving canal water, on a scale sufficient to show each field distinctly, so that all that would be necessary is, for the chokedar to note the number of the field, and the area could be calculated from the map. This certainly does not make it the zemindar's interest to economize the water any more than the present system does. Besides, the surveys to be of any use must be extremely minute, and consequently, expensive. Again, the boundaries between fields are not permanent, so that this would entail the making of new and costly maps every few years. I believe that this plan is to have a fair trial on the Baree Doab Canal.

Another suggestion was, to run a mud wall round each portion of irrigated land, and charge a certain water-rate for it yearly; this does not appear to require any argument to show that it is not practicable.

The Italian system of irrigation belongs to the 2nd Class; as also the plan proposed by Col. Goodwyn. An account of the former will be found at page 200 of Vol. II. of the Proceedings of the Society of Civil Engineers; and the latter is described in No. X., of the Thomason College Papers.

But, supposing we have contrivances giving a uniform discharge under varying heads, how are they to be regulated? For it would be absurd to suppose that the irrigator, who only requires water at intervals, should be expected to pay for an outlet constantly running; and as each man does not irrigate to the same extent, we should require the outlets to be of *all sizes*, which would probably throw everything into confusion.

[Plan of distribution proposed where bed of rajbuha is below, and full supply line above, water surface, is given in the *plate*].

From what has been stated, it appears that the element of time requires also to be taken into consideration. Now, as everything depends upon the time the outlet is open, it is evident that, unless there was an agent of the canal constantly present, the irrigator would be tempted to take more

than his due: therefore, to render the supervision free from this objection, the outlets in each beat must be confined to a certain point, and that there the chokedar should constantly reside. Supposing this plan to be adopted, to allow each zemindar to have a separate water-course and outlet from the rajbuha, would prove very inconvenient. To remedy this there should be one or more outlets on each bank at the head-quarters of the chokedar; from these Government kúls should be taken out and run for any distance that may appear necessary. The zemindars should connect their fields with the Government water-courses by the shortest cuts. At such points little masonry heads should be built, so that each man in turn may turn the whole of the supply into his own lands. The claims of the irrigators to take water can be easily adjusted by giving the largest and oldest irrigators the preference. From what has been already put forward, it would appear that the following afford the requisites for a satisfactory system for distributing the water and realizing the revenue, cheaply and fairly.

I.—The outlets must be confined to certain points, and here the chokedars should reside.

II.—Government kúls should be run out, as far as may be necessary, for each outlet, and irrigation should be carried on from these, and not direct from the rajbuha; this will do away with a large number of unsightly ditches, and as comparatively short cuts will connect the fields with the kúl, disputes about taking kúls through each others lands will be almost unknown.

III.—Some simple method of noting the time is necessary, and it should be such that any error (intentional or not) may be easily detected.

IV.—Half, at least, of the whole number of outlets should be capable of managing the largest supply that can be sent down.

As regards the 1st requirement, that all the outlets in a beat should be in the same place, no general rule could be laid down for their size, these depending on the wants of the irrigation and the size of the rajbuhas. However, their number must certainly be limited, or else the chief merit of the scheme, viz., its compactness, will be sacrificed. Again, the dimensions of the outlets must be limited, so that the discharges may not be so great as to prove unmanageable in the hands of a single irrigator, or so small that there results a great loss of time in watering each field.

As to the 2nd requirement, Government should construct the outlets and dig the kúls, the irrigators defraying the cost. All outlets and regu-

lating heads should be built on a standard plan, so as to avoid any chance of confusion in making up the revenue papers. On the judicious selection of sites for outlets depends the efficiency of the scheme. *Plate* LVIII. illustrates the method of lining out. Here the Government kûls, are shown by double ink lines, the short cuts made by the zemindars by dotted lines, and the single lines show the boundaries of the different irrigated plots.

To meet the 3rd requirement, a clepsydra should be so constructed that any error of time would be at once noticed on looking over the returns. This check might be a *double register*, with some sort of an arithmetical relation between the two. The theory of numbers would enable one to devise any number of such checks, that any but a very smart chokedar would would not be able to comprehend. To simplify matters, the clepsydra might be constructed to run continuously for 24 hours, and the time denoted in a decimal of a day. Any discharge from an ordinary sized outlet for a period not exceeding $\frac{1}{100}$ of a day, or 14·4 minutes, would irrigate but to a very small extent; therefore, the irrigator should be prohibited from using the outlet for less than 14·4 minutes. This would do away with any inclination on their part for making vexatious demands for petty supplies of water. Two equal cones of sheet-iron connected by a pipe, and fitted into a stout wooden frame, would give a clepsydra, cheap and substantial. It is proposed that something like the following form should be sent in by the chokedar daily or weekly. They might be arranged and used like ordinary cheque-books, or Form No. V. of the D. P. Works.

Name of irrigator.	Reading on clepsydra.			Gauge readings.			Signature or seal.	Remarks.
	On opening.	On shutting.	Difference.	On opening.	On shutting.	Difference.		
Abdoolla,	1 / 1_a	2 / 2_a	3	4 / 4_b	5 / 5_b	6	Lumberdar Khoda Bux's seal. Abdoolla's seal.	Watered rice crops, by 3rd head from outlet, &c., &c.

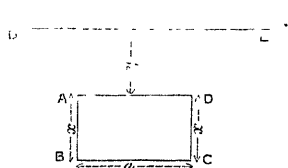
Unless complaints are made, we have only to deal with columns 5 and 6. Taking the gauge reading, we look into the table of discharges for the discharge corresponding to this head of pressure, and multiplying it by the

time, we find the quantity that is to be debited to the irrigator's account. To save the last calculation, tables in the following form might be drawn up:—

0 Foot.										30 A
	0	1	2	3	4	5	6	7	8	9
·05										
0·10										
0·15										
0 20										
0 25										
0 30										
0·35										
0 40										
0·45										
0·50										
0·55										
0·60										
0·65										
0 70										
0·75	...	...	...	...	...	...	A			
0·80										
0·85										
0 90										
0·95										
1·00										

Now, supposing a zemindar has had the use of the outlet for 0·36 of 24 hours, the mean head of pressure during the time it was opened being 0·75 feet. Turning over the pages of our book of tables till we see 1 foot (in big letters) in the left hand, and 30 A in the right hand corner of a page, we find that A^x is the value of what he has received, and this, in the case of making up the revenue papers, may show the money value, and for working out discharges, the actual volume.

By the head of pressure, I mean the difference between the level of water in the kúl and rajbuha, and supposing this head never exceeded 3·0 feet, 300 calculations of discharges would give the work done per unit of time to every hundredth of a foot; the value to every tenth of a foot might be checked by actual experiment and the rest interpolated. These 300 calculations × the 100 units of time (0·24 of 24 hours) would give a total of 30,000 products, or a set of tables showing the discharge under heads varying from 0 to 3·0 feet, and for any length of time not exceeding 24 hours.

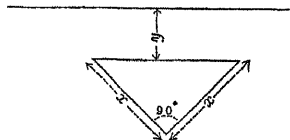
The checks necessary for verifying the correctness of the chokedar's reports have been already considered. We may now examine the relative value of simple orifices, whose discharge varies as the square of the head pressure, and outlets contrived to discharge equal volumes in equal spaces of time. The objections to the latter are, that requiring certain mechanism more or less elaborate, it is probable that men in charge would be always putting them out of order; and it is also very likely that the silt would injure them or cause them to give incorrect results. In the case of rectangular or triangular orifices whose areas vary inversely as the head of water, the complicated nature of the mechanism required would render their use almost impracticable. The following may be taken as an illustration. Here ABCD is a rectangular orifice, whose base BC is constant and equal to a; AB its height varies inversely as the square root of the head of pressure, and is put $= x$; DE, which shows surface level of water in rajbuha; and $y =$ depth to upper edge of orifice—putting the discharge $=$ D, we have

$$D = ax \times \sqrt{2g\,(y + \tfrac{1}{2}x)\,c}$$

where x and y are the unknown terms, c the co-efficient of discharge, and $g = 32{\cdot}2$.

Fig. 2, will show the practical application of this equation.

Here ACB is the curve of which x and y are the co-ordinates, x being measured along BE and y along DE. C is a float sliding freely on the curve and on the vertical bar, FG, of the regulating apparatus. For calculation, the above equation may be reduced to the form—

$$y + \tfrac{1}{2}x = \frac{B}{x^2}, \text{ where } B = \frac{D^2}{2a^2gc} - a, \text{ a constant quantity.}$$

Again, if we take a right-angled triangular orifice, as shown in figure, the equation would be $D = \frac{1}{2}\,x\,\sqrt{2\,g\,(y + \frac{1}{2}\sin 45^\circ)}\;c$ which reduced to the form $y + \frac{1}{2\sqrt{2}}\,x = \frac{2\,D^2}{2gc\,{}^2x^4}$ gives an equation more complicated than the former.

The simplest module is an iron shutter with a slit in it—working in water-tight grooves, and rising and falling by means of floats with the

supply in the rajbuha. To give accurate results this would require a clear fall.

As, however, all complex mechanical contrivances are liable to get out of order, it is believed that the simple outlet and a good set of tables would prove the most suitable. With such a system it is probable that the irrigating capabilities of canals would be developed to the utmost extent —it would entail scarcely any interference with the zemeendars, and act as a spur to the more enterprizing. If given a fair trial, many of the details could certainly be greatly simplified and improved by the suggestion of experience.

E. S.

Sept. 28th, 1865.

No. CLXVIII.

SUPERSTRUCTURE OF BOAT BRIDGES.

Design for an improved Superstructure for the Boat Bridges on the Lahore and Peshawur Road. BY COL. A. TAYLOR, R.E., C.B., *Superintending Engineer.*

To the Secretary to the Punjab Government, P. W. Department. 28th May, 1867.

WHEN boats and superstructure were first prepared for boat-bridges over the Ravee, Chenab, Jhelum and Indus rivers, on the line of the Grand Trunk Road, the pattern of beam, which came up from Bombay with the teak built boats in 1845, was adhered to.

The beams were made 30 feet long and 10 × 6 inches scantling, and each beam crossed one boat and one bay. Their ends overlapped one foot, and each boat therefore supported 28 running feet of roadway.

Even in those early days, however, when our deodar forests were in full vigor, great difficulty was experienced in getting sound beams 30 feet in length, and recourse was had to scarfing, which was attended with two serious objections, viz., the scarfed beam was much weaker than the natural beam, and frequently gave way; and, again, the iron work used to form the scarf, necessarily projected above the level of the wood-work and prevented the roadway planks from bearing evenly on all the beams, and this was a cause of damage to them; there was also the further objection, that the boats were amply buoyant enough to support a much longer piece of roadway than 28 feet, and so they unnecessarily blocked up the surface of the river.

These evils were most appreciated and felt at Attock, and gradually trussed beams were introduced there, of 30 feet in length, which gave a clear water-way between the boats of 28 feet instead of 16 feet. This was found to be a great improvement, for which Major Sandilands deserves the chief credit. It was, however, accompanied by a drawback—the weight of passing loads was thrown entirely on one gunwale at a time, and the rocking motion of the boats was greater than was desirable.

Lately these trussed beams have been introduced on the Chenab and Jhelum—and, I think, on the Ravee and Beas—and being alive to the necessity of reducing the amount of the rocking motion which their use has hitherto entailed, I made several experiments, when at Wuzeerabad, in the last winter, in concert with the Executive Engineer, Mr. Willson, which have resulted in an amount of success that was not quite anticipated.

I have now drawn up a sheet of drawings giving the full details of a system of superstructure, the result of these experiments, which developes the full advantage of the trussed roadway beams, and at the sametime entirely stops the objectionable rocking motion of the boats under a heavy concentrated moving load, which their use has hitherto entailed. It differs little from that in use on the Indus, at Attock, and in part at the bridge over the Chenab, at Goojrat, excepting in the introduction of stiffening planks and stiffening chains [*Figs.* 2, 4, and 8, and 6, 7, and 8], which prevent the boats from rocking.

I introduced these stiffening chains and planks when I was at Wuzeerabad in the early part of February last, and Mr. Willson informs me that they have not given the very least trouble since.

This system of Boat Bridge Superstructure, besides its superior efficiency and durability as compared with that hitherto in use, has the advantage of considerable economy, amounting to about Rs. 6 per foot run of bridge; or to Rs. 16,800 in the first cost of a bridge of 100 boats.

I would strongly recommend its introduction on all the ferries on the Trunk Road, from Lahore upwards.

I may, perhaps, with advantage, add, that all the boats and superstructure in use at the bridges in question were built and prepared on designs which I drew up many years ago, under Sir Robert Napier's instructions; so that my present recommendations merely supersede those which I myself made in 1850, after long experience of their working.

Proposed Superstructure for Boat Bridges.

It consists of the following component parts :—

1. Gunwale pieces, *gg*—[*Figs.* 1, 2, 5.]
2. Trussed beams, *kk*—[*Figs.* 1, 2, 10, 11, 12, 13 and 14.]
3. Stiffening beams, *aa*—[*Figs.* 1, 2, 4 and 5.]
4. Cross beams, *bb*—[*Figs.* 2 and 5.]
5. Stiffening planks, *cc*—[*Figs.* 2, 4 and 8.]
6. Stiffening chains, *ee*—[*Figs.* 1, 3, 4, 6, 7 and 8.]
7. Rough wedges, *hh*—[*Figs.* 1, 3 and 4.]
8. Ordinary roadway planks, *dd*—[*Figs.* 1, 4, 5 and 9.]
9. Railing planks, *ff*—[*Fig.* 15.]

1.—*Gunwale pieces.* See *gg*—[*Figs.* Nos. 1, 2 and 5].

Each is a single piece of timber 14½ feet long and 8 × 8 inches scantling, secured to the gunwale by two bolts of round iron of ¾-inch diameter.

It has four notches of 1 inch in depth, to receive both the trussed and the cross beams, and two deep notches, to receive the stiffening beams, of such dimensions as to bring the top surface of the trussed and of the stiffening beams to a level. *Fig.* 5 shows all details.

2.—*Trussed beams.* See *kk*—[*Figs.* 1, 2, 10, 11, 12, 13 and 14].

They may be each of a single beam 30 feet long and 7 × 7 inches scantling, or each may be built of four pieces bolted together by round bolts of 1 inch diameter, as shown in the drawings. Each beam runs in over the boat 1 foot, and rests on the gunwale piece in a notch 1 inch deep.

3.—*Stiffening beams.* See *aa*—[*Figs.* 1, 2, 4 and 5].

These are stout beams of 10 × 6 inches scantling, placed, as shown in the *Plate*, two to each boat. Each should, if possible, be a single piece of timber 26 feet 8 inches long, but may be in two pieces scarfed together. They are let into the gunwale pieces to such a depth as to bring their upper edges and those of the trussed beams to a true even surface.

4.—*Cross beams.* See *bb*—[*Figs.* 2, 4 and 5].

Are 7 × 7 inches scantling and 13 feet 2 inches long, and rest on the gunwale pieces in notches 1 inch deep. They merely rest on the gunwale pieces, and are not fastened to them.

5.—*Stiffening planks.* See *cc*—[*Figs.* 2, 4 and 8.]

Each plank consists of two pieces. One main piece 14 feet long and 12 × 3 inches scantling, and a minor piece (spiked to it as shown in *Fig.*

4) 12 feet long 8 inches wide, and of such depth as to compensate for the difference in thickness between the trussed beams and the stiffening beams (*kk* and *aa*) which in the *Plate* is 3 inches. They are placed, as shown in the *Plate* near the ends of the stiffening beams, and in every case immediately under a roadway plank.

Each stiffening plank is tightly lashed at each end to the roadway plank immediately above it, so as to allow no play whatever, by means of a chain here designated

6.—*A Stiffening chain.*—Which is shown in detail in *Figs.* 6, 7 and 8, and as regards its general application, in *Figs.* 1, 2 and 3.

Such a chain is passed round each projecting end of every stiffening plank, and of the roadway plank immediately over it; the hook with which it is provided at one end is passed into the nearest link, and everything is then brought home by the use of a rough wedge, *hh*.

The centre of each chain is secured to the under part of the stiffening plank by a stout staple [*Fig.* 8], which passes entirely through the plank, and is clenched on the upper side. The object is to prevent the chain from being lost in the confusion which often attends the dismantling of a bridge in a hurry, and often in the dark and in heavy weather.

7.—*Rough wedges.* See *hh*—[*Figs.* 1, 3 and 4.]

May be about 18 inches long. Their use is obvious.

8.—*Ordinary roadway planks.* See *dd*—[*Figs.* 1, 4, 5 and 9.]

Are 14 feet long, 3 inches thick, and as nearly 12 inches wide, as may be practicable.

The width for 6 inches at each end is to be reduced by 3 inches, as shown in *Fig.* 9.

Each plank is to be furnished with two hard wood cleats 3 × 2 inches, securely spiked on—see same figures.

9.—*Railing planks.* See *Fig.* 15.

Each plank is from 17 to 17½ feet long, and they may be placed at any convenient distance apart. The railing bars may be bullies of about 5 inches diameter, supported on treenails of 1½-inch diameter of hard dry wood.

A. T.

No. CLXIX.

NOTE ON RESERVOIR MASONRY DAMS.

By Lieut.-Col. Fife, R.E.

In the "Professional Papers" for August, Vol. IV., a section of the proposed Dam in the Moota valley is given in *Plate* XLVI., and as the subject of the best section for works of this nature is peculiarly interesting at the present moment, when it is contemplated to carry on works of irrigation over a great part of our Indian possessions, the drawings attached to this paper will probably be considered valuable.

The Barrage d' Almanza was constructed in the 16th century, and is in excellent condition, which proves the general soundness of the design.

The Barrage de Gros Bois is also an old work. It has shown signs of failure and has been buttressed. The batter in this case is on the water side, and the section is recommended in the "Aide Memoire." It may be well adapted for an ordinary foundation, as its tendency to oscillate on a yielding foundation when the reservoir is alternately full and empty, may be less than when the batter is outside, but it is not well suited when a hard foundation is attainable and where a great height of Dam is necessary.

The Barrage du Furens is a recent work. Its height is 164 feet. The great pressure induced by such an immense column of masonry and water led the very ingenious Engineer, M. Delocre, who designed the Dam, to adopt the principle of equal pressure, and hence the curved faces and comparative lightness of the superior part of the section, which, at first sight, would appear almost too weak to retain the great head of water to which it is exposed. The thickness at top would no doubt have been still lighter,

but that it was necessary to guard against the effect of the ice, which in that latitude attains a thickness of about 2 feet, and when broken up by a sudden thaw is driven by the prevailing wind with great violence against the masonry, which has thus to bear the most severe shocks, in addition to the ordinary action of the waves.

The Barrage du Ban is another, and more recent, design, on the equal pressure principle. It differs from the Barrage du Furens in having a higher pressure limit. The lower part of this profile is intended to show what the form would have been, had the height of the Dam been exactly equal to that on the Furens.

The information respecting these works has been extracted from a Memoire by M. Delocre, a translation of which for the use of the irrigation Department in the Dekkan is now under preparation, and will shortly be published.

J. G. F.

POONA,
19*th October*, 1867.

No. CLXX.

DETAIL OF WORKING ON THE GREAT TRIGONOMETRICAL SURVEY.

(*2nd Paper*).

Recording observations.—It is not however sufficient to be skilful and scrupulous in the manual and optical processes of observing; equal care and attention must be bestowed on the registry of the data in the angle books, otherwise the care and skill bestowed on the observations will be entirely wasted.

An error in reading off a micrometer, or in writing down the reading, will produce just as great a discrepancy in the work as if the eye had made an error of the same extent in observing.

The observer should therefore give out the degrees and minutes in an audible voice, and the writer should repeat them while he is writing down. Unless this precaution be taken, errors may arise from peculiar pronunciation or defective hearing. Similarly, the readings of the micrometer heads should be given out distinctly to the nearest tenth of a second, and duly repeated by the writer. The figuring on the micrometer heads is seldom neatly executed, and a liability sometimes exists to mistake 30″ for 50″, and *vice versâ*, which, if it occur in the microscope, would affect an angle by nearly 7″, or the mean of the whole twenty-four angles by four-fifths of a second. Mistakes of this and similar kind can only be avoided by strict attention. The writer should examine when the observations are repeated, whether any reading is discrepant, and should give due notice to the observer of such an occurrence.

The book in which observations are recorded is called an *angle book*, and

two of these books are kept on each series, one of which is used in the observatory, and called the "Original Angle Book," the other is a transcript of the former, and is termed the "Duplicate Angle Book." Of these, the former, when completed, will be transmitted to the India House, and the latter retained, as a record, in the Surveyor General's Office. The headings of the columns in the angle book are so explicit that no farther explanation seems necessary.

The angle book should on no account ever be suffered to fall in arrears. The original should be examined by two computers, and attested by their signatures, and the name of the observer should be recorded. The duplicate should be compared with the original by two persons, and attested by their signatures. It is a standing rule, in order to exclude errors, that all computations and comparisons should be performed independently by two persons, and attested by their signatures; and, unless such precautions have been observed, the results are considered untrustworthy as final work.

Observations should never be recorded on loose scraps of paper, or in pencil in rough books. The original record is always the most valuable document, and the labor of copying, besides being expensive, causes delay.

It is usual to add up all the angles observed at any one zero together, and divide them by the number, by which means you get as many sets of means as there are zeros, each mean being considered as an integral observation.

It is a fixed rule never to reject an observation, unless there be some obvious error in it. The circumstance of its differing, however widely, from the mean, is not a sufficient cause for its expunction.

Notwithstanding all the precautions which may be taken in making the observations, and recording them with fidelity and precision, it will be found that every mean angle is nevertheless burthened with small residual errors, which it is impossible entirely to eliminate, and which must therefore be dispersed in the subsequent office computations, agreeably to certain rules. These errors arise partly from imperfections in the instrument, and in the observer, and some part of them may also be attributed to other circumstances beyond our control. For instance, the image of an observed object is subject to distortion, on account of the rays of light passing through a medium of very variable density and temperature.

There is no reason to conclude that the vertical refraction is all in the normal of either extremity of the trajectory; but supposing this to be a

rejectaneous consideration, still smoke and various vapours perpetually rising from the earth, have probably not an uniform density at a given height above the surface, and the ray, in its passage through these, must unquestionably be liable to lateral as well as vertical refraction. We see, in fact, both by night and day that this cause is perpetually in operation; for the small disk of an Argand lamp, which is only twelve inches in diameter, and in a clear, settled atmosphere is reduced to a luminous point, swells out sometimes for several nights in succession into a broad ill-defined blaze, subtending occasionally two minutes of the horizon, and vibrating more like a sheet of fire than an object intended for accurate intersections, whilst the visible disk of the heliotrope, formed by limiting the rays to an aperture of two inches diameter, is even wilder and more straggling.

The only method of overcoming these sources of irregularity is to await a favorable state of the atmosphere, and be prepared to profit by it when it offers itself. Such occasions occur for day observation almost every sunny day for a shorter or longer period, between half-past three p.m. and sunset. The lamps are also frequently well adapted for observation from sunset to past midnight, especially in the early part of the season, but at other times they are steadiest from after midnight till about sunrise.

In hilly countries, when the stations are placed on lofty peaks, with deep intermediate valleys, objects are less disturbed by atmospheric causes than under other circumstances. Very good observations may then be obtained for an hour or two after sunrise; but, in general, however promising the apparent state of the atmosphere may be at sunrise, it can rarely be depended on. It is at this period of the day that mirage is most conspicuous. Two or three heliotropes are sometimes seen piled one above the other, or placed side by side, and then, uniting together, form columns or pillars of fire subtending several minutes, although produced by the rays of light passing through an aperture limited to two inches in diameter. This kind of lateral refraction is however too conspicuous to betray, but there is another insidious sort which ought carefully to be guarded against, because at the time it is in operation, the visible disk of the lamp or heliotrope appears at first sight small, well-defined, and steady; if, however, it be carefully bisected on the wire, and then watched, it will be found after the lapse of a few minutes, gradually to diverge to one side, and after a shorter or longer time, will again move off slowly in another direction. This

treacherous state of the atmosphere is very frequently in operation, and the only remedy is to watch carefully, and adjust the position of the telescope so that the object may appear to diverge equally on each side of the wire. With this precaution, good observations can be made, but each intersection occupies several minutes of time, and the observations proceed very slowly.

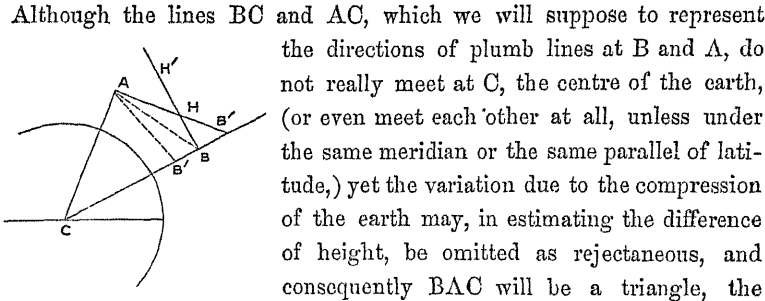
The accordance, or otherwise, of angles taken at the same zero, enables an observer to judge of the accuracy of his intersections, and the average errors of the triangles will show how far care and precaution have succeeded in eliminating the imperfections of the instrument, and other sources of error.

As perfect freedom from error is unattainable, success can only be judged from comparative approximation to the truth, and to enable an observer to form a fair estimate of his labors, compared with previous operations of approved merit, a table is subjoined showing the errors of ten consecutive triangles, taken from the reports of the undermentioned Series.

Table exhibiting the Errors of Ten consecutive Triangles of the undermentioned Series.

No. of Triangle.	Great Arc Series.	Amua Series.	Pilabit Terai Series	North Long. Series.	Chendwar Series.	Bombay Long Series.
	3-foot Theod. T. and S.	18-inch Troughton.	15-inch Cary.	18-inch Inst by Col. Everest and Said Mohsin.	18-inch Troughton.	18-inch Dolland.
1	− 0·31	+ 0·71	− 0·79	+ 1·99	+ 1·52	− 1·04
2	− 2·75	+ 3·58	+ 2·07	− 0·45	+ 0·84	− 0·39
3	+ 0·10	+ 0 07	− 2·97	− 1·12	− 2·36	+ 1·92
4	− 0·06	+ 0·23	+ 1·58	− 0·78	+ 1 64	+ 1·11
5	− 1·18	− 1·80	− 2·48	− 0·68	− 0·32	− 1·70
6	+ 2·72	− 1·21	− 3·92	− 0·39	+ 0·50	+ 0·11
7	+ 0·12	− 3·20	− 0·33	+ 4·41	+ 0·62	+ 0·24
8	+ 1 09	− 1·89	− 3·49	+ 0 02	+ 0·88	+ 0·34
9	− 3·32	+ 0·39	+ 2·19	− 0·88	− 0·36	− 0·03
10	− 0·05	− 0·42	− 1·61	+ 2·20	− 0·38	+ 2·98
	1·17	1·35	2·14	1·29	0·94	0 99

VERTICAL ANGLES.

The relative heights of the stations of a trigonometrical survey are deduced upon the following principles:—

Although the lines BC and AC, which we will suppose to represent the directions of plumb lines at B and A, do not really meet at C, the centre of the earth, (or even meet each other at all, unless under the same meridian or the same parallel of latitude,) yet the variation due to the compression of the earth may, in estimating the difference of height, be omitted as rejectaneous, and consequently BAC will be a triangle, the angle at C being the angular distance between the two stations on the earth's surface. Now AH, BH′ drawn prependicular to the radii will represent the planes of the horizon, consequently though B is more elevated than A, still it may stand at an angle of depression. Let A and B be the angles of depression at A and B, then it is easy to see that

$$C + (\tfrac{1}{2}\pi - A) + (\tfrac{1}{2}\pi - B = \pi,$$

or

$$A + B = C.$$

If one of these angles be an angle of elevation, the principle will remain the same; for, by writing $-$ E instead of B, the formula is still $A - E = C$.

Suppose now that both A and B appear raised by refraction, and the angles become $A - \delta A$, $B - \delta B$, or $E + \delta E$; then calling these new values A′, B′, or E′, the equation will be transformed to

$$C - (A' + B') = \delta A + \delta B,$$
$$\text{or } C - (A' - E') = \delta A + \delta E.$$

It is usual to suppose an equality between δA and δB, and putting each equal to ρ, the mean terrestial refraction, we get

$$\rho = \tfrac{1}{2}\left\{ C - (A' + B') \right\}$$

$$\text{or} = \tfrac{1}{2}\left\{ C - (A' - E') \right\}$$

If an isosceles triangle be made, by setting off $CB' = CA$, then BB′ will be the difference of height; also since $\angle B'AH = \tfrac{1}{2} C \therefore B'AB = \tfrac{1}{2} C - A = \tfrac{1}{2}(B - A) = \tfrac{1}{2}(B' - A')$ since $\delta A = \delta B$.

The angle BAB′ is called the subtended angle, because the difference of height is subtended thereby; call this angle S. Then if c be the length of the chord of the angle C, the difference of height will be deduced from

the equation $\frac{c \times \sin S}{\cos B} = c \times \sin S \times \sec B = c \times \sin \frac{1}{2}(B' - A') \times \sec B$, or $c \times \sin \frac{1}{2}(A + E) \times \sec B$. This equation is quite rigorous, and must be used when the depression is great, and consequently the difference of height considerable. For instance, when one station is on a lofty mountain, and the other in a low plain, the vertical angles may be very large, and the difference of height several thousand feet. But when A and B are small we may substitute unity for cos B, and then the ordinary formula for small differences of altitude becomes $\delta h = c \times \sin S$.

Several other considerations must now be made. The angles at both A and B are observed with an instrument which is elevated by a quantity a above the point whose height is sought. The corresponding angular value, therefore, or $\frac{a}{c \sin 1''}$, is a correction to be subtracted from all angles of depression, and added to all angles of elevation.

It sometimes happens that the vertical angles are taken to the top of an insufficient platform, which after being visited is raised; let the absolute height thus added be p, then $\frac{p}{c \times \sin 1''}$ is a correction which is to be subtracted from all angles of depression, and added to all angles of elevation, observed prior to the augmentation, in which case the new platform is treated as part of the mountain.

Daylight angles are often taken to the top of the flag-staff, or to an object raised above the station mark, in which case $\frac{f}{c \sin 1''}$ is to be applied positively to all depressions, and negatively to all elevations, f being the height of the object or staff.

Lastly, c to be accurate should be corrected for the height of the given station (A) above the sea, because c is the geodetic distance, nn', given in the triangle sheets, whereas the true distance AB′ is the element required in these computations. Therefore let h be the height of the given station (A) above the sea level, and r' the radius of curvature, then $r' : r' + h :: c : c + \delta c$, or, $r : h :: c : \delta c = \frac{c\,h}{r'}$ in which c may, as before, be taken for the measured chord, or measured arc, as given in the triangle sheets.

But it is the logarithm of $c + \delta c$, and not the natural number δc, that

is required in the computations, and it will be more elegant, as well as expeditious, to deduce the correction to the log. of the geodetic distance. This correction is always additive, and may be found from the following formula:—

$$\text{Ar. Co. log. } r' + \text{log. M} + \text{log. } h,$$

the natural number answering to which, carried to 7 places, is the correction required for log. *c*. The term M of the foregoing formula is the modulus of the decimal system of logarithms.

The problem of determining the relative heights of two stations A and B rests upon the foregoing mathematical principles, and the practical part of the operation obviously consists in carefully measuring with the instrument at each station, the altitude or depression of the others.

It will be recollected that in page 5 it was assumed for granted that the refraction at both stations is the same; but, in order that this equality may become a probable occurrence, the back or reciprocal vertical angles ought, rigorously speaking, to be taken at one and the same instant.* But as that cannot always be managed, the next best method is to be careful to observe them about the same hour from noon, for then the errors caused by terrestial refraction are more likely to compensate each other. The best period of the day for observing verticals is the time of minimum refraction, which usually occurs about 2-45 to 3-45 in the afternoon. Long experience has proved that reciprocal vertical observations, taken to heliotropes at the period of the day above indicated, give the most accordant results, and may therefore be confidently relied on. If the stations are not visible at the time of minimum refraction, the precaution should be taken of observing them simultaneously, by means of two instruments and two observers.

Four sets of observations, two with the face each way, are sufficient at each station, and every occasion should be used, when the rays cross each other and form separate series, to get as many points of verification as offer themselves.

Vertical observations taken with the face each way, that is to say, with the face of the vertical circle in one instance to the left hand, and in the next to the right, are called *collimated* observations; because the mean of

* This was done on the Great Indian Arc, in crossing the plains of Hindostan, because the vertical angles were there subject to the influence of extraordinary refraction and mirage, on account of all the rays grazing along the surface of the ground.

the two faces gives a vertical angle free from error of collimation, which is not the case with a single face.

The method of observing is as follows :—The instrument should be duly levelled and adjusted previous to the time of minimum refraction; and as soon as objects are steady, or nearly so,* direct the telescope to one of the principal stations, and having clamped the vertical circle, bisect the object with the horizontal wire, and note the hour and the minute at which the observation was made. Now read off the microscope of the vertical circle, according as the vertical angle may be an elevation or a depression, and let the readings be duly recorded in the angle book; release the clamp; turn over the telescope 180° in altitude, and the instrument round 180° in azimuth; bisect the same station again, and record the readings as before, together with the hour and minute of time at which the bisection was made. The mean of the two observations will give one collimated vertical angle. Repeat the last observation as before, and then reverse the instrument, and take another observation, which will complete the second collimated vertical angle. If these two be accordant they will suffice; otherwise a third, and even a fourth, ought to be taken. Now direct the instrument to another station, and take the vertical angles in the same manner, and in that way proceed until all the surrounding stations have been observed; but if the objects begin to rise, which will be ascertained from the depressions diminishing, or altitudes increasing, it will be necessary to desist for that day, and reject any observation which may have been made after the time of minimum.

When you arrive at a station which has been observed from one in rear, the back or reciprocal observations must be taken within a minute or two of the corresponding times. If any atmospheric change should appear to take place intermediately to the observations of the reciprocal vertical angle, the equality between the refractions, which the nature of the problem demands, is likely to be destroyed, and therefore too long a space of time ought not, if possible, to be allowed to elapse before the reciprocal observations are made.

* Heliotropes are seldom perfectly steady till 4 or 4½ p.m., but at that period they are beginning to rise at the rate of a second per minute. Although they may appear a little agitated at 3 p.m., still the refraction is then least, and the observations give the best results. In fact, any error arising from the agitated aspect of the heliotrope will be much less injurious than refraction, and indeed may be counteracted in a great measure by multiplying the observations, because the agitation of the disk does not produce a constant error in one direction, as happens in the case of uncertain refraction.

In page 418 it has been remarked that corrections must be applied for the height of the instrument, and also for the height of the observed objects. The former should be carefully measured by the observer, and the latter by the men in charge of the heliotropes and lamps, so that on arrival at each station the heights of the objects may be duly measured, and noted in proper form.

Hitherto we have only considered the case of principal stations at which the back, or reciprocal, vertical angle can readily be observed; but it is clear that if the amount of refraction were known, the relative heights could be deduced from verticals taken at one extremity of a ray, whereby the height of intersected secondary points could be ascertained.

It is usual to estimate the terrestrial refraction in terms of the contained arc, that is to say, $\rho = n\mathrm{C}$, whence $n = \frac{\rho}{\mathrm{C}}$, and by the supposition of an equality between the refractions at the extremity of a ray, we obtain the value of n from all the observations at every principal station by the formula in page 417.

The mean of all the values of n at any station may therefore be adopted as a mean ratio of refraction to contained arc at that locality, and this mean refraction may without risk be applied to correct any single vertical angle taken to any secondary point; consequently, if D be the observed depression of that secondary point, and C the contained arc due to its distance, then $\mathrm{D} + n\mathrm{C} = \Delta$ will be the true depression cleared of refraction. Let the unobserved reciprocal vertical be D' or $-\mathrm{E}'$, its corresponding value in vacuo being Δ, then as $\mathrm{C} = \Delta + \Delta'$, therefore $\Delta' = \mathrm{C} - \Delta$, and the subtended angle $\mathrm{S} = \frac{1}{2}(\mathrm{D} - \mathrm{D}') = \Delta - \frac{1}{2}\mathrm{C} = \mathrm{D} + n\mathrm{C} - \frac{1}{2}\mathrm{C}$; or, for an elevation, $\mathrm{S} = \mathrm{E} - n\mathrm{C} + \frac{1}{2}\mathrm{C}$.

Upon this principle may be deduced the relative height of a secondary point, from a vertical angle observed at one station only, without any corresponding back observation; but, in order that the factor n may be used with confidence, the vertical should be taken about the same time from noon as the other verticals from which the value of n is derived. Some observers adopt a mean refraction deduced from the whole series of triangulation, or they employ the factor deduced from other geodetical operations of known celebrity, such as the English and French trigonometrical survey operations; but the factor obtained from observations made on the spot appears preferable, as better adapted to existing circumstances

of locality and atmosphere. It may be premised, *à priori*, that refractions observed in the climate of France or England are not likely to assimilate with others made in the torrid zone, nor is the refraction at a station little elevated above the sea, likely to be the same as the refraction on a lofty mountain, where the barometric pressure and temperature are so much smaller. Every consideration therefore seems to combine in favor of the adoption of a local value of the factor of refraction.

If a secondary station be observed from several principal stations situated at very various distances, the refraction can be inferred by another process, viz., by assuming a variety of different values for n, and finally adopting that value which furnishes the most accordant results. This method was adopted by Mr. H. Colebrooke, in determining the height of the mountain Dhawalagiri, situated to the north of Nepal.

The following extract from his paper is taken from Vol. XII. of the "Asiatic Researches":—

Station.	Distance in Miles.	Intercepted Arc in Degrees.	Altitude by Observation.	Height, allowing for Refraction.						
				$\frac{1}{3}$	$\frac{1}{6}$	$\frac{1}{8}$	$\frac{1}{11}$	$\frac{1}{12}$	$\frac{1}{13}$	$\frac{1}{14}$
		° ′ ″	° ′							
A	89·35	1 17 51	2 48	24875	26663	27110	27476	27558	27626	27855
C	102·85	1 29 36·6	2 19	24348	26716	27308	27792	27900	27991	28294
D	136·35	1 58 48	1 22	21338	25494	26554	27384	27573	27773	28286
			Mean,	23520	26091	26784	27551	27677	27797	28145
			Extreme Difference,	3537	1222	774	408	342	365	439

"It is apparent from inspection, that the observations at the stations A and D agree best; and if that computation be nearest the truth, wherein the extreme differences are least, the conclusion will be, that the height is about 27,550 feet; such being the elevation deduced from the mean of observations calculated according to middle refraction."

Correspondence.

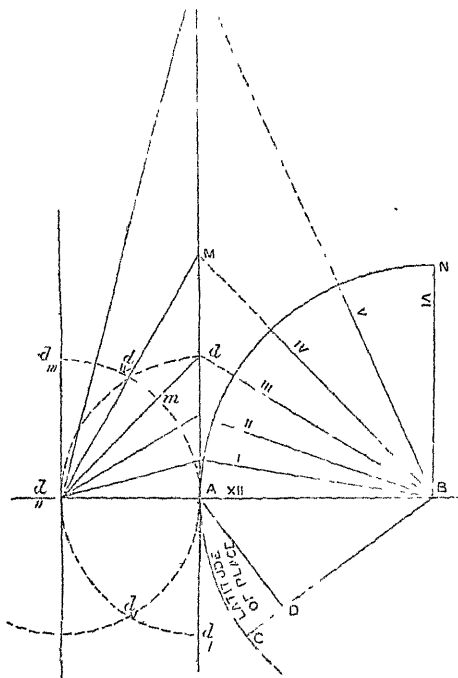
The Editor acknowledges, with thanks, the receipt of the following Papers:—Iron Sleepers on Indian Railways—Floods on the E. I. Railway—St. Andrew's Kirk, Bangalore—Preparation of Asphalte—Mysore Irrigation—Economy of Steam in India—Wedge-bricks for Arches—Traffic on Roads, Railways and Canals—New Canal Module—Artificial Hydraulic Lime—Iron Mile Posts—Berar Specifications—Rewaree Slate Quarries—Irrigation in Ceylon—Analysis of Mysore Limes—Trials of De Lisle's Clinometer—Irrigation in Spain—Milroy's Excavating Apparatus—Tree Spurs on the Ravee—Sand Pumps for Well Foundations—Irrigation of Sindh—Maynee Tank Project—Bhatodee Tank Project—Completion of Mitrow Canal—Col. Rundall and Col. Anderson on the Ganges Canal—Iron Girder Bridges on the Delhi Railway—Lahore Central Jail—Brick-making by Machinery—Reports on the Hurdwar Stone Quarries—Screw-Pile Light-houses for India—Irrigation in Gujerat, Candeish and the Deccan—Embankments and Spurs on the Markunda River—Embankments in Bengal 1866—Preparation of Timber on the Boucherie system—Experimental Metalling on the Agra and Bombay Road—Work Rates on the Ganges Canal—The Alignment of Rajbuhas—Distribution of Canal Water—Upper Indus River Works—Regulation of Selye and Damooda Rivers—Reservoirs for the Damooda River—Launching Girders on the Jubbulpore Railway—Notes on the Slide Rule—The Hindostan and Thibet Road—Colonel Fraser on Light-houses—Superstructure of Boat Bridges—Laws of Water in Motion—Notes on Retaining Walls, Part III.—Tracing Hill Roads.

CONSTRUCTION OF SUN-DIALS.

To the Editor.

SIR,—It is very often useful in this country to know how to make a sun-dial. Perhaps the following simple plan may be interesting to your readers. It is not to be found in books.

Draw any line d_{II} AB to represent the meridian, make AB = ½ length of intended sun-dial.

Lay off the angle ABC = latitude of place. Draw AD perpendicular to BC. From centre A with radius Ad_{II} = AD describe the semicircle $d_{I}\ d_{V}\ d_{II}\ d_{I}$ draw AM perpendicular to AB, and produce it indefinitely both ways; and draw $d_{II}\ d_{III}$ parallel to AM. Mark the points d, d_{III}, d_{II} from d_{II} as centre with radius AD describe the semicircle $d, d_{IV}\ d_{II}\ d_{I}$ mark the points d_{IV}, d_{V} joint $d\ d_{V}$ mark the point m. Then the arc Am = 45° Ad_{IV} = 60°, and arc md_{IV} = 15°. From this divide the arc Ad_{II} = 90° into six equal arcs of 15°. Join $d_{II}, d_{IV}, d_{III}, m$, &c., and produce these lines to meet AM in M, d, &c., and join BM; B, d, &c. These are the hour lines, reckoned from XII. o'clock on the meridian.

The Gnomon must be shaped to the latitude ABC with angular point at B directed towards the south in north latitudes.

The forenoon hour lines must be laid off in the same way, on the contrary side of AB.

By subdividing the arcs md_{IV}, &c., lines in the same way may be obtained for every five numbers.

Yours faithfully,

H.

BAHRAETCH,
12th December, 1866.

To the Editor.

MY DEAR SIR,—I think it would be useful to the Profession generally, if room could be found, in some of the future series, for the late Government Reports on the

Godavery and the Ganges works. The outer world has not the opportunity of obtaining copies of these interesting reports, and in these days when so many are turning their thoughts to the subject of Irrigation and Water Conservancy, and so much money is being spent on them, these and kindred reports cannot fail to prove acceptable.

One would like to know more of the Madras system of Irrigation, of the many tanks and anicuts, and system of sluices.

Sheets No 74 and 75 of the Trigonometrical Survey Maps of India, exhibit the most extraordinary system of Tank creation that can be seen in any part of the world, showing that, during the dynasty of the Kings of Wurungal, the Telinganas were giants at water conservancy. We see every nullah, great and small, bunded up, and tank below tank created till the whole country looks gemmed. This is what we want done throughout India, but Government alone could not do it ; no, nor if it was backed by all the surplus wealth and energy of England, could it do more than make all the Main Canals and large storage works. The people must assist in this work of regeneration : every village and town community must be induced to lend a willing help in making the minor channels and subsidiary tanks ; and for this we must have something more attractive than a 30 years' settlement, or even a permanent one.

We sadly want Commissioners of Irrigation in the several Provinces ; men gifted in several ways, capable of not only guiding the efforts of the people, but also of persuading them into assisting in such noble works. I can't believe it possible that such an extraordinary system of Irrigation and Tank formation as surrounds Hyderabad and Wurungal can have been the result of ought than rulers and people working harmoniously.

For our great storage tanks, which must be made, we have yet to hit upon the best arrangement of sluices, capable of drawing off immense bodies of water under heads varying from 30 to 150 feet. For these works no precedents exist in Europe or Asia, and yet who can doubt the necessity for such great storage lakes, if we are ever to prevent the annual mighty floods, and economise the rain-fall for useful purposes ?

Another great question is that of Waste Weirs. There are many immense tanks in Southern India which have failed from these being made too small. Once in a hundred years comes a mighty fall of rain, and the Waste Weir is found wanting ; or again, there is an annual silting up going on in the bed of the tanks, and the people fail to keep the bunds up in due proportion, so that the calingulas which were formerly sufficient, become no longer capable of discharging the flood water. One sees many magnificient sites for tanks, but when a site for the necessary Waste Weir is sought for, it is not to be got, except at a vast outlay in cutting away the crest of a hill. In such cases, it strikes one that it would be advisable to erect a masonry bund, and allow the flood water to discharge itself over the same. The question here would be, How about the fall of large bodies of water for heights varying from 30 to say 100 feet ? Could not a cushion of water, made of varying depths, according to the height of fall and quantity of falling water, be designed, so as secure the foundations of the bund from injury ?

Excuse my addressing you on these points, as they seem to me to be such as require a multitude of councillors.

Yours faithfully,
R. M. B.

To print such Reports, as R. M. B. asks for, "*in extenso*," would simply be to exclude every other subject from these Papers. Interesting, doubtless, as Irrigation Works are to most Engineers in India, it is necessary to consult the tastes of all. Meanwhile, these Reports are not so inaccessible as R. M. B. supposes, and copies can generally be procured on application to the Press of this College, or to the Public Works Secretariat, by any one really interested in obtaining them.

In the present number R. M. B. will find much information on the subject (Tank Irrigation) which he names, and the remainder of Major Sankey's Report, which will be given next time, will be found equally interesting.

The method of building Waste Weirs proposed by R. M. B. is very common, especially in Mairwara and Ajmere (*see* Colonel Dixon's work on the subject), and is generally resorted to when a separate escape for flood water cannot be conveniently provided. When it *can*, however, the latter method is evidently preferable.

In contrasting the Public Works made by the ancient and modern rulers of India, as is so often done to the disadvantage of the latter, the system of forced labor, by which such great results were achieved must not be lost sight of. Such a system is a great power, where, as is always the case in a despotic Government, the intelligence of the rulers is in advance of that of the people; and there is no doubt that to this system, India was mainly indebted for her public works in former times. But whatever the capabilities of such a system, or the hardships inflicted by it, we have deliberately abandoned it, and it is impossible to recur to it now. We must perforce wait until education brings the people up to the level of the Government, before we can hope to see them work with us in constructing Public Works.—[ED.]

To the Editor.

DEAR SIR,—I have read, with much interest, the Clinometer Reports printed in your number of "Professional Papers" for August, and should be glad if you would allow me space for a few observations on them.

Colonel Bell of the Bombay Engineers was the first to use the reflecting level for tracing roads. His instrument was heavy, having a large pear-shaped bulb of gun-metal. A long screw, with large heads and a clamping nut passed through the bulb, and served to adjust the instrument to the required slope, with the assistance of pegs set out with a spirit level. The defects appeared to be its weight, and its want of self-adjustment.

I proposed to remedy these defects by diminishing the size of the bulb, and substituting a square sliding bar with a clamping screw, for Colonel Bell's long screw. Messrs. Cooke and Sons made up one on this pattern, but it was found to have this inconvenience, that the high slopes 1 in 5 to 1 in 20 had very open divisions, while in the flatter gradients, the divisions were too close together to be read by the naked eye.

Mr. Alfred Cooke then devised the instrument in its present form. The object of the double bar is to equalize the divisions.

The instrument is first adjusted to level, with both bars home against the stop, *g*. The light bar is then set back until the mirror is inclined at 1 in 50, and a stop is screwed in. After that the principal divisions are marked experimentally, and the remainder are filled in by interpolation. In every case, except where levels are required, the light bar must be set to the stop, *h*, before the heavy bar is set to the required division on the limb.

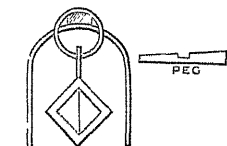
It seems to me that there must be some error in the drawing of your *Plate* XXXII.; the stops *g* and *h* in *Fig* 1 are shown at the same end of the arc, where they cannot possibly both be; and unless the position of the stop *h* in the other figures differs very widely from my instrument, there would seem to be some error in them also. I enclose a correct tracing from a drawing prepared for the "Bombay Builder," showing the correct setting for 1 in 20.

You will now see that I have very little claim to have the instrument called by my name, and that Colonel Bell or Mr. Cooke ought to have the credit of the invention.

Now, as to the objections: *The action of the wind* is considered a serious one. Lieut. Osborn, R E., who used it with great success, got over this difficulty by giving his hand a very slight vibration, which sufficiently neutralised the oscillations caused by the wind to enable him to take good observations. A little practice will enable any observer to do the same.

Increase of size.—This would be sacrificing the advantage of handiness and portability; and, besides, cause greater fatigue to the hand and more unsteadiness in use.

Wire across mirror.—My instrument was provided with one at first, but was soon rejected, as it caused great fatigue to the eye in the attempt to bring three points together, viz., the reflected image of the eye, the direct image of the vane, and the cross wire. The latter is really unnecessary, as the centre of the pupil and the centre line of the vane are the proper objects to determine the observation and the small size of the mirror renders it easy to bring the reflected image of the eye nearly in the line of the diagonal. A slight error in this respect is of no consequence in road making.

I do not quite understand the objections made by Mr. Stanley Alexander to the suspension of the instrument. A chain an inch long would allow the mirror to turn and twist about, and the knife edge and link gives as delicate an adjustment as that of an ordinary balance. When placed in a wind-guard, as Colonel Bell's was, the ring should be passed through a slit in the lever, and secured by a peg with a notch to prevent slipping. This would always keep the face in the proper direction.

The instrument must of course be held at the proper distance from the eye, but this is soon learnt by practice.

The trouble of verifying the setting at each observation is very slight, compared to that of adjusting a theodolite.

Some gentlemen have suggested tripod stands, but in many cases these could not be used for want of slope to set them up. No provision was made for any stand at all; what is really required is a long stick with a crutch, which any carpenter can make in five minutes, of bamboo. It should be long enough to bring the mirror to the level of the eye when the hand rests on the crutch. Lieut. Osborn preferred a long rest, 3 feet long, to support both hands. In fact every observer would soon find out what sort of rest would suit him best.

I now come to Lieut. Browne's report, which is the most unfavorable of all. It occurred to me that he may have omitted to set the small bar to its proper stop when laying out his gradient of 1 in 20; I therefore, with the assistance of Captain White, R.E., marked off a distance of 26·4 feet from a wall, and took the difference of level between a mark made with the two bars of the instrument in their proper positions, and again with the two bars together. The difference was exactly 0·32, which multiplied by 100, would give the exact error he found in half a mile.

Perhaps Lieut Browne will be kind enough to verify this, and ascertain whether this supposition is correct. Otherwise either his instrument must have been a bad one, or his "personal equation," as astronomers call it, must be very large.

Lieut. Osborn's report, which is perfectly reliable, shows that a considerable amount of accuracy can be obtained with the instrument.

A clinometer seems to be in common use on your side for tracing roads. A short description of it would be interesting to us. We generally use the theodolite here.

Believe me, yours truly,

A. De Lisle.

Bombay,
10th September, 1867.

QUERY.

To the Editor.

Dear Sir,—The objection to the employment of steamers on canals is, that the waves or swell caused by the paddles are injurious to the banks. Might not this be practically avoided by having a series of paddles, individually of small width, on a long narrow framework carrying merely the machinery, the cargo being stowed away in a train of barges? On an irrigation canal, where the supply may be considered unlimited, the lockage would not be more expensive even if the whole train, without being disconnected, were transferred to the different levels.

In canals solely designed for navigation, as is the case in England, the supply is limited, and every cubic foot of water that is saved in lockage is so much gained; but on Indian canals there is always an enormous surplus going over the falls, so that chambers of the smallest possible dimensions are really not wanted. Instead of the usual chamber, about 16 feet in width and 100 feet long, large reservoirs might be constructed capable of containing a whole fleet of boats. Provided the gates were well

protected by long spreading wing walls, the rest of the work would not need revetment, and most likely the reservoir might be built for less than the massive masonry chamber. The former might be filled and emptied as quickly by carefully distributed inlets and outlets as the latter ; the boats only would feel the fluctuation in level whatever the quantity withdrawn or supplied, and the working of the gates depends only on the depth, and not the superficial extent, of the chamber or reservoir. Fuel for the steamers could be easily grown on the canal spoil; besides, a large supply could be obtained from trees growing spontaneously on the water's edge, if these were allowed to grow to any size, and thus an annual expenditure for cutting jungle not needed. Still water canals connecting the principal places of commerce with the main or irrigation canal, would give a prefect system of water communication. In a mutiny a railway is more easily damaged than a canal.

Yours faithfully,

S.

Punjab, 4th Oct., 1867.